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SPUR
Simulation of Production and Utilization of Rangelands

Documentation and User Guide

ABSTRACT

Wight, J. Ross, and J.W. Skiles, eds. 1987. SPUR: Simulation of Production and Utilization of Rangelands. Documentation and User Guide. U.S. Department of Agriculture, Agricultural Research Service, ARS 63, 372 p.

The SPUR model is a comprehensive rangeland simulation model developed to provide information for research and management. It is composed of five basic components: (1) climate; (2) hydrology; (3) plant; (4) animal; and (5) economic. The model is driven by daily maximum and minimum air temperatures, precipitation, solar radiation, and wind run. SPUR simulates the daily growth of individual plant species or functional species groups and uses preference vectors based on forage palatability, location, and abundance to control plant utilization. Animal growth is simulated on a steer-equivalent basis, and net gain is used to calculate economic benefits. The hydrology component calculates upland surface runoff volumes, peak flow, snowmelt, streamflow, and upland and channel sediment yields. This publication contains the model documentation and a user guide with complete instructions for model operation, resource materials for determining the values of input variables and parameters, and examples of model inputs and outputs.

KEYWORDS: rangeland model, rangeland hydrology, plant model, livestock model, climate model, range management, range research, range economics

As the chapters were prepared by different individuals, there is some variation in style and units of measurement. These variations should not detract the attention of the reader. Any questions should be referred to the authors of the specific chapters.

This publication is a product of the combined efforts of many individuals. The editors extend special thanks to S.L. Hennefer, A.L. Huber, S.J. Stillings-Jackson, D.M. Potter, and C.Y. Wentzell of the Northwest Watershed Research Center staff for proofreading, typing, creating graphics, and preparing the camera-ready copy.

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PREFACE

A proposal entitled "Improved Management and Production of Western Rangelands Using Predicting Models and Remotely Acquired Data," submitted by C.H. Herbel and W.O. Willis, was perhaps the first formal step toward the development of a range modeling effort by the Agricultural Research Service (ARS). Subsequently, a research planning workshop on range modeling was held in Fort Collins, CO, April 20-21, 1978. The participants of this workshop recommended that an ARS range modeling effort be started immediately. The major goals stated were to (1) increase use of modeling among range scientists as a research technique to guide and improve ongoing research and provide data bases and submodels for use in more comprehensive models and (2) develop comprehensive models that could be used effectively as planning and decisionmaking tools in the management of rangeland resources and administrative and research programs.

On September 18, 1980, Dr. T.B. Kinney, Jr., ARS Administrator, stated that "ARS can and should act as the catalyst for a coordinated national effort to develop a model(s) for rangeland ecosystems." According to Dr. Kinney, the general purpose of this model would be to (1) predict range productivity, (2) evaluate the effects of various management practices, (3) help transfer research results among different range ecosystems, and (4) determine range research needs.

The SPUR modeling effort was started in September 1980 with the organization of a coordinating committee composed of R.A. Evans, R.H. Hart, G.B. Hewitt, C.L. Hanson, L.J. Koong, K.G. Renard, P.L. Sims, J.R. Wight, and G.E. Carlson and J.C. Ritchie of the ARS National Program Staff. At coordinating committee meetings in November 1980 and February 1981, objectives, organization, and procedures were established. A range modeling workshop was held in May 1981 to (1) review, refine, and adopt the modeling approach, (2) establish lines of action and time tables, (3) organize model component work groups and assign specific tasks within each work group, and (4) identify data sets for model testing and validation. Following the workshop, the climate, hydrology, plant, animal, and economic components of the model were developed independently at the locations of the respective lead scientists. Interfacing the components into a comprehensive rangeland model was the responsibility of project modelers located at Boise, ID.

In February 1983, a SPUR model symposium was held in conjunction with the annual meeting of the Society for Range Management. At this symposium, a publication containing a narrative description of the SPUR model components was presented. From 1983 to 1986, the SPUR model was tested, modified, refined, validated, and analyzed, and the manuscript of the model documentation and user guide prepared.

SPUR is a comprehensive rangeland ecosystem model developed as a tool for both research and management and represents the combined efforts of many scientists. It includes a pasture or field-scale version that emphasizes the plant and animal processes and interactions and a basin-scale version that emphasizes the hydrology of small basins. Model components were developed using state-of-the-art technology drawing from models such as ELM (Grassland Simulation Model), and SWRRB (Simulator for Water Resources in Rural Basins). No new field research was conducted as a basis for its development. SPUR is a physically based model but includes some empirical functions. Because of the unavailability of complete data sets, only a limited amount of validation has been possible and usually on a component basis.

Bringing the components together and making SPUR more than a collage of functions and subroutines was a major task for E.P. Springer and J.W. Skiles, the project modelers.

This publication contains the complete model documentation (Part I) and a user guide (Part II) for both the field-scale and basin-scale versions of the model. The complexity of SPUR and the quantity of information required to run it are reflected in Part II. This section was prepared under the direction of J.W. Skiles and includes detailed instructions and diagrams that should significantly enhance understanding and operation of the model.

The code for SPUR was developed on a VAX 11/750 using an enhanced FORTRAN IV language. The code can be furnished to anyone interested in using the model. Transfer of the model code and sample data file can be done on magnetic tape or 5 1/4-inch, double-density diskettes. Requests for copies of the SPUR code should be sent to the project coordinator along with a blank magnetic tape with the user's tape-reading specifications or with two blank diskettes.

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CHAPTER

1. INTRODUCTION TO SPUR

J.R. Wight

Rangelands are described as lands on which the native vegetation is predominantly grasses, grasslike plants, forbs, and shrubs that are suitable for grazing or browsing, and lands revegetated by native or introduced species to provide a cover that is managed like native vegetation (Kothmann 1974). They are often referred to as residual land, areas left after cultivation has reached the frontiers where inadequate water, difficult topography, soil instability, or other factors make cultivation economically and ecologically unfeasible.

Rangelands occupy about 40 percent of the earth's land surface (Branson et al. 1972). About 332 million hectares (35 percent) of land in the United States is classified as rangeland (USDA, Forest Service 1980). Although their per-unit-area productivity is relatively low, rangelands collectively constitute a vital world resource. They provide grazing for domestic animals and food and habitat for wildlife species. They are important in terms of recreation and as sources of oil, coal, and other minerals. They constitute vast watersheds that provide water for onsite and downstream uses.

The rangeland resource is a diverse and complex array of ecosystems and is inherently more fragile than cropland. It is characterized by steep slopes, shallow soil mantles, and a native plant cover that is in delicate balance with the environment. About 71 percent of U.S. rangelands have slopes greater than 12 percent as compared with only 10 percent of the croplands (USDA, Resources Conservation Act Coordinating Committee 1980). If the vegetation cover is reduced beyond some critical point by mismanagement, natural disasters, or combinations of both, erosion may accelerate to the extent that entire soil mantles are lost. Once an accelerated erosion cycle begins, it is often self-sustaining. For example, loss of vegetation cover through overgrazing may result in substantial soil loss which, in turn, reduces a range site's ability to produce an adequately protective vegetation cover, and erosion continues to accelerate.

Rangeland resources are relatively difficult to manage. Vast areas of low-per-unit area productivity place economic limits on the intensity of management, and thus, animal manipulation is often the only viable management tool. Management responses on rangelands are difficult to measure due to extreme spatial and temporal variation of the vegetation. Responses to treatment and management are very slow, often requiring a decade or more to become measurably evident. Variations in annual climate, especially precipitation, are also extreme with year-to-year changes of 100 percent or more being a common occurrence. These climatic variations confound treatment and management effects, making experimental results difficult to interpret.

Modeling offers a new tool for both research and management. As research tools, models (1) help sharpen the definition of hypotheses, (2) enhance communication, (3) help define and categorize the state of knowledge, (4) provide an analytical mechanism for studying the system of interest, (5) can be used to conduct simulated experiments instead of real-world experiments, (6) provide a key to determining the progress of research, (7) provide a method for breaking down information, and (8) can be used for prediction (USDA, Agricultural Research Service 1978).

As management tools, rangeland models are effective for predicting hydrologic, plant, and/or animal responses to environmental and management inputs, and for assessing economic benefits of management decisions. Through stochastic processes, model outputs can be framed within confidence intervals, and management decisions can be made based on various levels of probability of occurrence.

The use of simulation models in range research and management is relatively new and has received considerable impetus through the IBP Grassland Biome Study headquartered in Fort Collins, CO during the late 1960's and early 1970's. The Grassland Simulation Model (ELM) (Innis 1978) demonstrated that the processes within a rangeland ecosystem could be modeled and provided methodology and direction for future modeling efforts. The ELM model also demonstrated the utility of models as research tools and aids to resource management.

This publication describes SPUR, a comprehensive rangeland ecosystem model which was developed as a tool for both research and management. The SPUR model is composed of five basic components: climate, hydrology, plant, animal (both domestic and wildlife), and economics. The climate component operates outside the model and provides the rainfall, maximum and minimum air temperatures, solar radiation, and wind run data needed to drive SPUR. These data can be obtained from weather records or generated stochastically within the climate component. The stochastic generation of the climatic variables or parameters enhances the utilization of the SPUR model for long-term simulations and enables the model to be applied to areas where availability of climatic data is limited.

The hydrology component calculates upland surface runoff volumes, peak flow, snowmelt, upland sediment yield, and channel streamflow and sediment. It also calculates a daily soil-water balance that is used to generate soil-water suction pressures that control plant growth. Surface runoff is estimated by a modified Soil Conservation Service curve number procedure and soil loss is computed by the Modified Universal

Soil Loss Equation (Williams and Berndt 1977). Snow accumulation and melt routines in the hydrology component use air temperature as the controlling factor.

In the plant component net photosynthesis is the basis for predicting forage production. Species can be grown individually or lumped together in functional groups such as warm-season grasses or cool-season grasses. Carbon and nitrogen are cycled through several compartments including standing green, standing dead, live roots, dead roots, seeds, litter, and soil organic matter. Soil inorganic nitrogen is also simulated. Photosynthesis is controlled by temperature, soil water, nitrogen, and leaf area. The model simulates competition among species plus the impacts of grazing on vegetation. Inputs required include the initial biomass content of each compartment and parameters that describe species photosynthesis, respiration, and nitrogen utilization.

The animal component considers both domestic livestock and wildlife as consumers. Detailed growth information is available for cattle on a steer-equivalent basis. Forage consumption is calculated for all classes of animals. Steer growth is computed by an adaptation of the Texas A&M Beef Model (Sanders and Cartwright 1979). The development of preference vectors based on forage palatability and site location to control plant utilization by animals is a unique feature of the model. Wildlife species, including insects, are considered as fixed consumers and allowed to have first access to the available forage.

Animal production or pounds of beef gain are used by the economic component to estimate the benefits and costs of alternative grazing practices, range improvements, and animal management options.

Two versions of SPUR were developed and are described in this publication: A grazing unit, or field-scale version, and a basin-scale version. The field-scale version can simulate the growth of up to seven plant species or functional groups. These species or functional groups can be grown on up to nine range sites within a grazing unit. The field-scale version can accommodate the resolution of the animal component to differentially graze a pasture based on the combined effects of the preference vectors. It provides pasture or allotment level managers with a method to simulate growth and grazing of the major plant species and animal production.

The basin-scale version is somewhat more complex. It provides a means of predicting quantities of runoff and sediment yield for basins of up to 2,500 hectares with up to 27 hydrologic units (drainages adjacent to a channel), and it retains the ability to simulate plant growth, grazing, and beef production. However, the resolution of these components is diminished relative to the field-scale version. The basin-scale version uses the watershed as a management unit and is designed for the land manager.

This publication represents the first phase of the SPUR project and describes a functional rangeland ecosystem model that requires considerable input and knowledge of the system in order for it to be operated effectively. The first phase of SPUR is directed primarily to the scientific community where it will serve as an effective research tool and be exposed to continued testing, validation, and refinement. However, it can also be used effectively as a management tool.

Phase II of SPUR will be a continuation of the development and refinement of the SPUR model with emphasis on its resource management applications. Ease of use and the ability to simulate scenarios addressing key management concerns will be its main features.

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2. CLIMATE GENERATOR

C.W. Richardson, C.L. Hanson, A.L. Huber

INTRODUCTION

Climate and day-to-day variations in weather have major influences on range processes such as forage production, livestock water, insect dynamics, and erosion. The climate of a range site determines, in large measure, the type and quality of the forage species, type of grazing animals, and management systems for the site. Weather data are needed to assess the effects of climate on range processes and as inputs to range models.

Weather records for many range sites are insufficient to make the desired assessments. Therefore, one should have the capability of either generating weather data with the same statistical characteristics as the actual weather at the location or of using the location's weather records when they are available.

The climate generator described herein contains three options for utilizing available climatic data to generate a climatic record. These options are:

1. Read actual daily precipitation, actual maximum and minimum air temperatures, and actual solar radiation, and generate wind run.

2. Read actual daily precipitation and generate the other four variables (see 1. above).

3. Generate all five variables (see 1. above).

The user may have all five climate variables available and, therefore, will not need to use a climate generator. If this is so, the SPUR computer program will read daily precipitation, maximum and minimum air temperatures, solar radiation, and wind run from the climatological record at the specific location.

The subroutines in the field-scale version of SPUR utilize climatic data for one location per simulation. The basin-scale version of SPUR utilizes climatic data for one location on the basin except when measured precipitation data are available for more than one hydrologic unit. When precipitation data are available for multiple units, the data can be used to represent the precipitation input to each hydrologic unit.

CLIMGN, A MODEL FOR GENERATING DAILY WEATHER VARIABLES

A model called CLIMGN (climate generator) has been developed for generating daily values of precipitation, maximum temperature, minimum temperature, solar radiation, and daily wind run. The model is based on the procedure described by Richardson (1981) and the computer program described by Richardson and Wright (1984), but several assumptions have been made to simplify the use of the model and a wind generating component has been added. The model parameters which are required to generate new sequences of the weather variables have been determined for locations in the United States and are given in chapter 10, part II. A program to compute the required precipitation-generating parameters is also available and is described in the same chapter.

Several other models have been developed for generating sequences of daily weather variables (Jones et al. 1972, Bond 1979, Nicks and Harp 1980, Bruhn et al. 1980, Larsen and Pense 1981). These models, although based on sound statistical principles, lack the general applicability and ease of use afforded by CLIMGN.

Model Description

The CLIMGN program generates daily values of precipitation (P), maximum temperature (t_{max}), minimum temperature (t_{min}), solar radiation (r) and wind run (WIND) for an n-year period at a given location. The model is designed to preserve the dependence in time, the internal correlation, and the seasonal characteristics which exist in actual weather data for the location. Precipitation and wind run are generated independently of the other variables.

Maximum temperature, minimum temperature, and solar radiation are generated depending on whether the day is wet or dry.

Precipitation

The precipitation-generation component of CLIMGN is a Markov chain-gamma model. A first-order Markov chain is used to generate the occurrence of wet or dry days. When a wet day is generated, the two-parameter gamma distribution is used to generate the precipitation amount.

With the first-order Markov chain model, the probability of rain on a given day is conditioned on the wet or dry status of the previous day. A wet day is defined as a day with 0.01 inch of precipitation or more. Let $P_i(W/W)$ be the probability of a wet day on day i given a wet day on day i-1, and let $P_i(W/D)$ be the probability of a wet day on day i given a dry day on day i-1. Then:

$$\begin{aligned} P_i(D/W) &= 1 - P_i(W/W) \\ P_i(D/D) &= 1 - P_i(W/D) \end{aligned} \tag{1}$$

where $P_i(D/W)$ and $P_i(D/D)$ are the probabilities of a dry day given a wet day on day i-1 and the probability of a dry day given a dry day on day i-1, respectively. The transition probabilities are, therefore, fully defined given $P_i(W/W)$ and $P_i(W/D)$.

The density function of the two-parameter gamma distribution is given by:

$$f(p) = \frac{p^{\alpha-1} e^{-\frac{p}{\beta}}}{\beta^{\alpha} \Gamma(\alpha)}, \qquad p > 0 \tag{2}$$

where α and β are distribution parameters and $\alpha(\Gamma)$ is the gamma function of α. The α and β are shape and scale parameters, respectively. For $0 < \alpha < 1$, the distribution has a reverse "J" shape. This shape is appropriate for precipitation amounts since small amounts occur more frequently than larger amounts. The gamma distribution was shown by Richardson (1982a) to be better for describing precipitation amounts than the simple exponential distribution.

The values of P(W/W), P(W/D), α, and β vary continuously during the year for most locations. In CLIMGN, each of the four precipitation parameters is held constant for a given month but vary from month to month. The values of each of the four parameters were determined by month for 139 stations in the United States. The parameters were defined using 20 years (1951-70) of daily rainfall data for each station. The rainfall parameter values are given in the User Guide, chapter 10, table 1. The parameters are used with a Markov chain-generation procedure and the gamma-generation procedure described by Haan (1977) to generate daily precipitation values.

Temperature and Solar Radiation

The procedure used in CLIMGN is based on the weakly stationary generating process given by Matalas (1967). The equation is:

$$x_i(j) = Ax_{i-1}(j) + \beta\varepsilon_i(j) \tag{3}$$

where $x_i(j)$ is a 3 X 1 matrix for day i whose elements are residuals of t_{max} (j = 1), t_{min} (j = 2), and r (j = 3); ϵ_i is a 3 X 1 matrix of independent random components, and A and B are 3 X 3 matrices whose elements are defined such that the new sequences have the desired serial correlation and cross-correlation coefficients. The A and B matrices are given by:

$$A = M_1 M_0^{-1} \tag{4}$$

$$BB^T = M_0 - M_1 M_0^{-1} M_1^T \tag{5}$$

where the superscripts -1 and T denote the inverse and transpose of the matrix. M_0 and M_1 are defined as:

$$M_0 = \begin{bmatrix} 1.0 & p_0(1,2) & p_0(1,3) \\ p_0(1,2) & 1.0 & p_0(2,3) \\ p_0(1,3) & p_0(2,3) & 1.0 \end{bmatrix} \tag{6}$$

$$M_1 = \begin{bmatrix} p_1(1) & p_1(1,2) & p_1(1,3) \\ p_1(2,1) & p_1(2) & p_1(2,3) \\ p_1(3,1) & p_1(3,2) & p_1(3) \end{bmatrix} \tag{7}$$

where $p_0(j,k)$ is the correlation coefficent between variables j and k on the same day, $p_1(j,k)$ is the correlation coefficient between variables j and k with variable k lagged one day with respect to variable j, and $p_1(j)$ is the lag-one-serial-correlation coefficient for variable j.

The correlation coefficients in equations 6 and 7 were determined by season from 20 years of temperature and solar radiation data for 31 locations in the United States. The seasonal and regional patterns of the correlation coefficients were described by Richardson (1982b). The seasonal and spatial variation in the correlation coefficients are relatively small. If the small variations are neglected and the average values of the correlation coefficients given by Richardson (1982b) are used, the M_0 and M_1 matrices become:

$$M_0 = \begin{bmatrix} 1 & 0.633 & 0.186 \\ 0.633 & 1 & -0.193 \\ 0.186 & -0.193 & 1 \end{bmatrix} \tag{8}$$

$$M_1 = \begin{bmatrix} 0.621 & 0.445 & 0.087 \\ 0.563 & 0.674 & -0.100 \\ 0.015 & -0.091 & 0.251 \end{bmatrix} \tag{9}$$

(The off-diagonal elements were calculated but not reported by Richardson (1982b).)

Using equations 4 and 5, the A and B matrices become:

$$A = \begin{bmatrix} 0.567 & 0.086 & -0.002 \\ 0.253 & 0.504 & -0.050 \\ -0.006 & -0.039 & 0.244 \end{bmatrix} \tag{10}$$

$$B = \begin{bmatrix} 0.781 & 0 & 0 \\ 0.328 & 0.637 & 0 \\ 0.238 & -0.341 & 0.873 \end{bmatrix} \tag{11}$$

The A and B matrices given in equations 10 and 11 are used with equation 3 in CLIMGN to generate new sequences of the residuals of t_{max}, t_{min}, and r, which are serially correlated and cross correlated with the correlations being constant at all locations.

The final daily generated values of t_{max}, t_{min}, and r are determined by multiplying the residual elements generated with equation 3 by a seasonal standard deviation and adding a seasonal mean using the equation:

$$t_i(j) = x_i(j)\, s_i(j) + m_i(j) \quad (12)$$

where $t_i(j)$ is the daily value of t_{max} (j = 1), t_{min} (j = 2), and r (j = 3); $s_i(j)$ is the standard deviation; and $m_i(j)$ is the mean for day i. The values of $m_i(j)$ and $s_i(j)$ are conditioned on the wet or dry status as determined from the precipitation component of the model. By expressing equation 12 in terms of the coefficient of variation (c = s/m) rather than the standard deviation, the equation becomes:

$$t_i(j) = m_i(j)\,[x_i(j)\, c_i(j) + 1] \quad (13)$$

The seasonal change in the means and coefficients of variation may be described by:

$$u_i = \bar{u} + C \cos(360 \frac{i - T}{365}) \quad i = 1, 2, \ldots, 365 \quad (14)$$

where u_i is the value of the $m_i(j)$ or $c_i(j)$ on day i, $\bar{u}$ is the mean of u_i, C is the amplitude of the harmonic, and T is the position of the harmonic in days (fig. 2.1). Values of $\bar{u}$, C, and T must be determined for the mean and coefficient of variation of each weather variable (t_{max}, t_{min}, r) and for the wet or dry condition. These values were determined from the 20 years of daily weather data for the 31 locations and are given in tables 2.1 through 2.5. There were no detectable differences in the means and coefficients of variation for t_{min} on wet or dry days. Therefore, the values of $\bar{u}$, C, and T given in table 2.3 describe the seasonal variation in the mean and coefficient of variation of t_{min} for both wet or dry days.

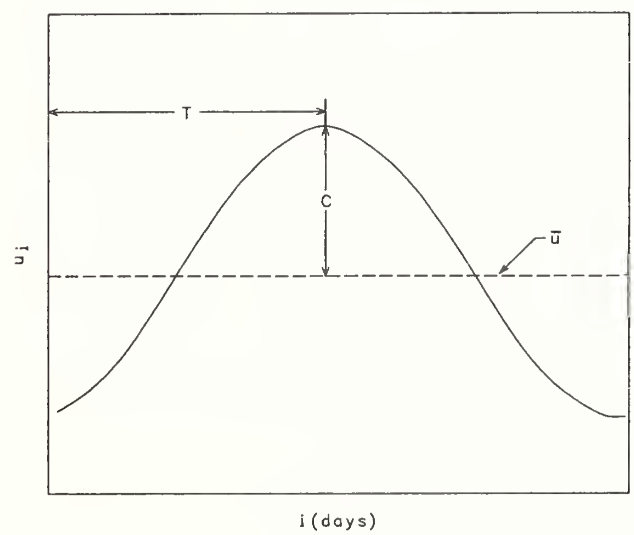


Figure 2.1
Definition of variables in seasonal description of temperature and solar radiation.

Some of the parameters in tables 2.1 through 2.5 are strongly location dependent, while other parameters do not change significantly with location. The values of T for all the descriptors of temperature (means and coefficients of variation of t_{max} and t_{min}) are near 200 days for all locations. Similarly, the T values for r are about 172 days (summer solstice) for all locations. Therefore, in CLIMGN, all the T values for temperature are assumed to be 200 days and all the T values for solar radiation are assumed to be 172 days.

The $\bar{u}$ and C values for t_{max} vary with location. The amplitude (C) of the mean of t_{max} for a given location was not significantly different on wet or dry days. The C's for the coefficient of variation of t_{max} are negative because t_{max} is less variable during the summer when the mean t_{max} is greatest. The values of $\bar{u}$ and C for the coefficient of variation of t_{max} are the same for either wet or dry days. The $\bar{u}$ values for the mean of t_{max} on wet days were signficantly less than for dry days. The other parameters for t_{max} on wet days were not required since they were not significantly different from the parameters of t_{max} on dry days. The values of $\bar{u}$ and C for the means and coefficients of variation of t_{min} all have a strong regional pattern.

Similar to t_{max}, C for the mean of r was not significantly different on wet and dry days. The values of u and C for the coefficient of variation of r showed no relationship to station location. The variation in each of the three parameters, among the 31 locations, is assumed to be sampling error. In CLIMGN, the parameter values are assumed to be constant at the average values.

The following notations will be used for the means ($\bar{u}$) and amplitudes (C) of equation 14 for t_{max}, t_{min}, and r:

TXMD - mean of t_{max} (dry), °F,

ATX - amplitude of t_{max} (wet or dry), °F,

CVTX - mean coefficient of variation of t_{max} (wet or dry),

ACVTX - amplitude of coefficient of variation of t_{max} (wet or dry),

TXMW - mean of t_{max} (wet), °F,

TN - mean of t_{min} (wet or dry), °F,

ATN - amplitude of t_{min} (wet or dry), °F,

CVTN - mean of coefficient of variation of t_{min} (wet or dry),

ACVTN - amplitude of coefficient of variation of t_{min} (wet or dry),

RMD - mean of r (dry), ly,

AR - amplitude of r (wet or dry), ly,

Table 2.1
Values of ū, C, and T for the mean maximum temperature on wet or dry days for 31 locations in the United States

City and State	Dry days ū (°F)	C (°F)	T (days)	Wet days ū (°F)	C (°F)	T (days)
Albuquerque, NM	71.0	23.1	195.9	64.8	24.4	200.6
Atlanta, GA	71.8	19.3	197.1	69.8	17.2	197.1
Bismarck, ND	55.5	32.4	201.7	48.8	32.1	199.4
Boise, ID	63.7	26.1	198.3	59.4	20.6	202.9
Boston, MA	59.3	24.0	202.9	58.2	20.7	209.2
Brownsville, TX	83.4	10.8	201.1	78.4	13.1	204.6
Caribou, ID	48.6	30.1	201.1	48.4	23.9	204.6
Charleston, SC	75.6	15.9	197.1	74.4	14.6	201.1
Cleveland, OH	60.0	25.3	203.5	58.6	25.1	201.1
Columbia, MO	66.0	25.5	200.6	64.0	23.8	201.1
Dodge City, KS	69.5	24.4	199.4	59.5	28.7	198.3
El Paso, TX	78.1	19.5	194.8	71.5	22.0	197.1
Ely, NV	62.5	23.5	203.5	54.5	23.1	206.3
Fresno, CA	76.7	21.0	200.6	69.4	16.8	208.1
Great Falls, MT	59.5	24.1	202.3	46.9	28.4	198.8
Grand Junction, CO	66.6	27.7	197.7	59.9	24.7	200.6
Greensboro, NC	69.8	20.5	197.7	67.6	19.2	196.5
Indianapolis, IN	62.3	26.4	200.0	62.0	23.5	200.6
Lander, WY	60.0	26.3	200.6	49.7	25.1	200.6
Little Rock, AR	73.7	21.8	198.3	70.6	19.9	199.4
Madison, WI	57.0	29.1	200.0	55.9	27.5	201.7
Medford, OR	68.3	22.6	198.3	60.9	16.3	203.5
Miami, FL	83.1	7.9	204.0	82.6	6.4	207.5
Nashville, TN	70.3	23.2	198.8	69.6	19.7	198.8
Oklahoma City, OK	72.6	22.4	199.4	66.1	24.1	200.0
Phoenix, AZ	85.5	19.8	200.6	76.8	20.7	205.8
Rapid City, SD	62.4	25.7	202.9	51.7	29.0	200.0
Salt Lake City, UT	65.3	27.3	199.4	59.6	23.5	204.6
San Antonio, TX	81.0	16.5	198.3	75.8	16.8	198.3
Sault Ste. Marie, MI	49.9	27.7	204.0	47.9	25.5	204.0
Spokane, WA	58.4	26.3	197.7	53.6	20.3	198.8
Mean	67.3	23.1	199.9	62.5	21.8	201.6
Standard deviation	9.5	5.2	2.4	9.8	5.3	3.4

Table 2.2
Values of $\bar{u}$, C, and T for coefficient of variation of maximum temperature on wet or dry days for 31 locations in the United States

	Dry days			Wet days		
City and State	$\bar{u}$ (°F)	C (°F)	T (days)	$\bar{u}$ (°F)	C (°F)	T (days)
Albuquerque, NM	0.11	-0.07	201.1	0.14	-0.07	201.1
Atlanta, GA	.12	- .08	201.7	.12	- .06	198.8
Bismarck, ND	.30	- .28	200.6	.32	- .28	197.7
Boise, ID	.15	- .07	201.7	.15	- .03	194.2
Boston, MA	.16	- .08	205.2	.16	- .06	215.6
Brownsville, TX	.07	- .05	194.2	.09	- .06	193.1
Caribou, ID	.26	- .23	200.6	.21	- .12	197.1
Charleston, SC	.10	- .07	200.6	.10	- .06	205.8
Cleveland, OH	.22	- .07	209.8	.21	- .13	205.8
Columbia, MO	.19	- .13	200.6	.19	- .13	201.1
Dodge City, KS	.17	- .11	204.0	.23	- .15	202.9
El Paso, TX	.09	- .05	198.8	.13	- .07	202.3
Ely, NV	.15	- .10	203.5	.17	- .06	198.3
Fresno, CA	.10	- .03	204.6	.10	- .01	199.4
Great Falls, MT	.21	- .14	201.7	.40	- .36	195.9
Grand Junction, CO	.14	- .09	200.6	.15	- .06	195.4
Greensboro, NC	.13	- .08	202.9	.15	- .07	202.3
Indianapolis, IN	.19	- .14	200.6	.18	- .12	203.5
Lander, WY	.19	- .14	195.9	.25	- .15	191.3
Little Rock, AR	.13	- .09	199.4	.14	- .09	197.1
Madison, WI	.22	- .17	199.4	.21	- .13	202.9
Medford, OR	.13	- .04	202.3	.13	- .01	204.0
Miami, FL	.05	- .03	204.0	.05	- .02	222.5
Nashville, TN	.15	- .11	200.0	.14	- .08	200.0
Oklahoma City, OK	.15	- .10	201.1	.18	- .12	198.3
Phoenix, AZ	.08	- .03	212.7	.09	- .02	194.2
Rapid City, SD	.22	- .15	201.1	.30	- .22	197.7
Salt Lake City, UT	.15	- .09	201.1	.17	- .07	197.1
San Antonio, TX	.09	- .06	198.8	.12	- .07	197.7
Sault Ste. Marie, MI	.24	- .18	204.6	.22	- .13	205.8
Spokane, WA	.16	- .08	194.8	.16	- .05	195.4
Average	.16	- .10	201.5	.17	- .10	200.5
Standard Deviation	.06	.06	3.7	.07	.08	6.3

Table 2.3.
Values of $\bar{u}$, C, and T for the mean and coefficient of variation of minimum temperature for 31 locations in the United States

City and State	Mean Wet or dry days $\bar{u}$ (°F)	C (°F)	T (days)	Coefficient of variation Wet or dry days $\bar{u}$ (°F)	C (°F)	T (days)
Albuquerque, NM	43.5	21.0	200.6	0.17	-0.13	202.9
Atlanta, GA	51.4	18.8	199.4	.16	- .13	198.3
Bismarck, ND	29.3	28.7	199.4	.65	- .90	200.0
Boise, ID	39.5	17.1	201.7	.22	- .06	187.9
Boston, MA	43.6	21.0	207.5	.20	- .18	199.4
Brownsville, TX	64.9	12.7	197.7	.11	- .08	196.5
Caribou, ID	29.8	25.1	205.2	.35	- .50	207.5
Charleston, SC	53.9	18.2	199.4	.16	- .12	195.9
Cleveland, OH	41.3	21.3	205.2	.29	- .16	203.5
Columbia, MO	44.7	23.3	200.6	.26	- .22	198.8
Dodge City, KS	42.9	24.2	201.1	.25	- .20	201.7
El Paso, TX	50.8	20.2	197.1	.15	- .11	199.4
Ely, NV	28.1	18.2	200.6	.45	- .45	194.2
Fresno, CA	48.7	13.3	201.7	.12	- .05	195.4
Great Falls, MT	34.1	20.6	204.0	.49	- .56	199.4
Grand Junction, CO	40.3	22.7	199.4	.23	- .20	196.5
Greensboro, NC	47.0	20.2	199.4	.20	- .14	196.5
Indianapolis, IN	42.3	22.6	200.0	.28	- .24	199.4
Lander, WY	31.7	22.5	200.6	.44	- .48	195.9
Little Rock, AR	51.4	20.5	197.1	.18	- .13	195.9
Madison, WI	35.1	24.6	202.3	.48	- .55	200.6
Medford, OR	40.6	11.7	20.40	.16	- .06	191.3
Miami, FL	68.2	9.1	206.3	.08	- .06	204.0
Nashville, TN	48.5	20.8	198.3	.22	- .17	198.8
Oklahoma City, OK	49.0	22.3	199.4	.19	- .15	200.0
Phoenix, AZ	56.5	19.5	204.6	.11	- .05	202.3
Rapid City, SD	34.5	23.8	202.3	.42	- .46	200.0
Salt Lake City, UT	38.9	19.8	200.6	.25	- .18	194.2
San Antonio, TX	58.0	17.7	197.7	.15	- .11	200.0
Sault Ste. Marie, MI	31.1	23.3	209.8	.61	- .80	208.7
Spokane, WA	37.4	16.2	201.1	.23	- .16	194.2
Average	43.8	20.0	201.4	.27	- .25	198.7
Standard deviation	10.1	4.2	3.1	.15	.22	4.3

Table 2.4
Values of ū, C, and T for the mean solar radiation on wet or dry days for 31 locations in the United States

City and State	Dry days ū (°F)	Dry days C (°F)	Dry days T (days)	Wet days ū (°F)	Wet days C (°F)	Wet days T (days)
Albuquerque, NM	520.4	224.6	171.1	285.2	226.7	180.9
Atlanta, GA	448.1	174.0	166.5	259.4	161.7	177.4
Bismarck, ND	401.0	266.1	171.7	271.1	181.2	174.0
Boise, ID	429.2	276.0	173.4	282.7	209.3	179.2
Boston, MA	388.0	218.5	168.2	201.9	142.5	176.9
Brownsville, TX	480.5	175.1	180.9	291.4	157.1	191.9
Caribou, ID	383.2	245.6	164.7	224.6	142.2	166.5
Charleston, SC	462.7	176.2	165.3	283.0	159.2	176.3
Cleveland, OH	383.6	244.4	171.1	244.0	176.7	175.1
Columbia, MO	430.8	226.7	174.6	258.7	185.7	178.6
Dodge City, KS	464.2	221.0	172.8	308.6	198.4	174.6
El Paso, TX	545.3	206.7	168.2	419.8	227.7	172.2
Ely, NV	486.4	241.5	172.2	341.4	174.6	171.7
Fresno, CA	462.1	259.4	172.8	292.9	175.6	170.5
Great Falls, MT	389.9	277.2	172.8	271.6	176.5	169.9
Grand Junction, CO	478.7	235.8	172.8	329.5	183.1	175.7
Greensboro, NC	434.4	184.2	168.2	263.2	170.8	172.2
Indianapolis, IN	407.1	224.5	172.8	248.7	179.5	176.9
Lander, WY	451.8	242.3	169.9	324.1	162.1	164.7
Little Rock, AR	438.1	195.7	169.9	254.0	174.3	179.8
Madison, WI	398.8	240.6	169.9	245.8	170.2	175.1
Medford, OR	425.9	298.6	174.6	271.9	192.0	174.0
Miami, FL	494.2	135.7	167.0	367.9	108.0	180.3
Nashville, TN	431.0	207.8	170.5	255.3	186.2	179.8
Oklahoma City, OK	449.3	194.3	174.6	270.1	180.6	178.6
Phoenix, AZ	516.0	208.9	165.9	360.7	195.7	180.3
Rapid City, SD	414.0	238.4	171.1	293.8	173.7	168.8
Salt Lake City, UT	462.8	267.2	172.2	309.1	200.1	176.9
San Antonio, TX	466.5	168.9	181.5	292.0	166.7	183.8
Sault Ste. Marie, MI	396.5	277.8	165.3	230.6	144.2	167.0
Spokane, WA	394.3	296.7	172.8	255.1	200.8	171.1
Average	443.1	227.4	171.1	284.1	176.9	175.5
Standard deviation	43.0	40.0	4.0	45.5	24.5	5.5

Table 2.5
Values of ū, C, and T for the coefficient by variation of solar radiation on wet or dry days for 31 locations in the United States

City and State	Dry days ū (°F)	C (°F)	T (days)	Wet days ū (°F)	C (°F)	T (days)
Albuquerque, NM	0.15	-0.05	190.7	0.32	-0.13	178.6
Atlanta, GA	.24	- .06	197.7	.56	- .22	194.8
Bismarck, ND	.26	- .07	190.2	.46	- .01	197.7
Boise, ID	.23	- .12	189.6	.44	- .12	178.0
Boston, MA	.28	- .05	182.1	.70	- .16	186.1
Brownsville, TX	.24	- .11	204.0	.52	- .19	211.5
Caribou, ID	.28	- .06	117.9	.55	- .08	90.2
Charleston, SC	.22	- .06	190.2	.52	- .17	197.1
Cleveland, OH	.32	- .12	180.3	.56	- .16	179.8
Columbia, MO	.28	- .11	200.0	.59	- .22	189.6
Dodge City, KS	.23	- .06	202.3	.52	- .13	181.5
El Paso, TX	.14	- .04	175.1	.33	- .13	172.2
Ely, NV	.17	- .04	197.7	.33	- .07	160.7
Fresno, CA	.21	- .15	186.7	.48	- .12	156.1
Great Falls, MT	.26	- .08	179.8	.43	- .04	111.6
Grand Junction, CO	.19	- .04	205.2	.38	- .10	176.3
Greensboro, NC	.24	- .05	193.1	.55	- .19	187.3
Indianapolis, IN	.29	- .12	197.1	.58	- .23	183.8
Lander, WY	.18	- .01	178.6	.38	- .02	118.5
Little Rock, AR	.26	- .10	192.5	.57	- .24	196.5
Madison, WI	.30	- .08	176.9	.59	- .13	179.2
Medford, OR	.26	- .16	184.4	.42	- .10	163.6
Miami, FL	.19	- .02	194.8	.35	- .05	222.0
Nashville, TN	.28	- .12	192.5	.56	- .25	191.3
Oklahoma City, OK	.26	- .07	200.6	.58	- .20	189.0
Phoenix, AZ	.14	- .04	169.9	.40	- .16	192.5
Rapid City, SD	.23	- .04	192.5	.43	- .04	131.2
Salt Lake City, UT	.22	- .10	184.4	.42	- .12	169.4
San Antonio, TX	.25	- .12	210.4	.53	- .23	205.2
Sault Ste. Marie, MI	.29	- .11	150.3	.54	- .04	111.5
Spokane, WA	.28	- .14	178.0	.44	- .09	154.9
Average	.24	- .08	186.6	.48	- .13	172.8
Standard deviation	.05	.04	17.6	.09	.07	31.1

CVRD - mean of coefficient of variation of r (dry), (assumed to be 0.24 for all locations),

ACVRD - amplitude of coefficient of variation of r (dry), (assumed to be -0.08 for all locations),

RMW - mean of r (wet), ly,

CVRW - mean of coefficient of variation of r (wet), (assumed to be 0.48 for all locations),

ACVRW - amplitude of coefficient of variation of r (wet), (assumed to be -0.13 for all locations).

These variables are defined graphically in figures 2.2, 2.3, and 2.4.

Precipitation and Temperature Corrections for Topographic Features

For most locations, the data generated with these procedures will have mean monthly precipitation and temperatures which are very close to the means obtained from actual data. Some differences will be caused by the temporal and spatial smoothing which is inherent in the model, topographic features of the location, or other factors. Procedures have been developed which provide for correction of these differences if actual mean monthly values are available and the user chooses to make these corrections. Use of the correction options provides generated daily values that compare closely with the monthly means derived from the actual observations. Use of the correction procedure requires that the actual monthly means, for the variable to be corrected, be input to the generation program. Mean monthly precipitation and/or temperatures for selected locations are available from many sources.

The precipitation correction factor for a given month is calculated as the mean monthly precipitation from actual data divided by the mean monthly precipitation generated with the Markov chain-gamma model. The generated, daily precipitation amounts are multiplied by the precipitation correction factor for the appropriate month to obtain a corrected precipitation amount.

The temperature correction may be based on either actual mean monthly temperature or mean maximum temperature and mean minimum temperature, depending on which type of data are available for the location. For mean monthly temperature, the temperature correction factor is calculated as the difference between the actual mean monthly temperature for the location and the mean monthly temperature generated using the parameters for the location. The generated daily maximum and minimum temperatures are both corrected by adding the correction factor to the generated temperatures. When mean monthly maximum and minimum temperatures are available, correction factors for the maximum and minimum temperatures are computed independently.

Wind

The wind component of CLIMGN provides for the generation of daily wind speed values. Wind speed is generated using the two-parameter gamma distribution expressed as:

$$f(v) = \frac{v^{\lambda_j} e^{-\frac{v}{\gamma_j}}}{\gamma^{\lambda_j} \Gamma(\lambda_j)} \tag{15}$$

where λ_j and γ_j are distribution parameters for month j, and v is daily wind speed. The values of λ_j and γ_j are estimated using the method of moments by:

$$\lambda_j = \frac{\bar{v}_j^2}{s_j^2} \tag{16}$$

and:

$$\gamma_j = \frac{s_j^2}{\bar{v}_j} \tag{17}$$

where $\bar{v}_j$ is the mean wind speed (mph) for each month, and s_j is the standard deviation of daily windspeed. The Climatic Atlas of the United States (U.S Department of Commerce 1968) contains values of $\bar{v}_j$ for many locations. The mean annual wind speed ($\bar{v}_y$) is available in the Climatic Atlas and the standard deviation of hourly wind speed on an annual basis (s_h) can be computed from the table on page 78 of the Atlas. By experimenting with the standard deviation of hourly and daily wind speeds for several locations, a correction factor of 0.7 was found to be appropriate for converting the standard deviation of hourly wind speed to the standard deviation of daily wind speed.

If the coefficient of variation of daily wind speed (c_v) for a location is assumed to be constant over the year, c_v may be estimated by:

$$c_v = 0.7 \frac{s_h}{\bar{v}_y} \tag{18}$$

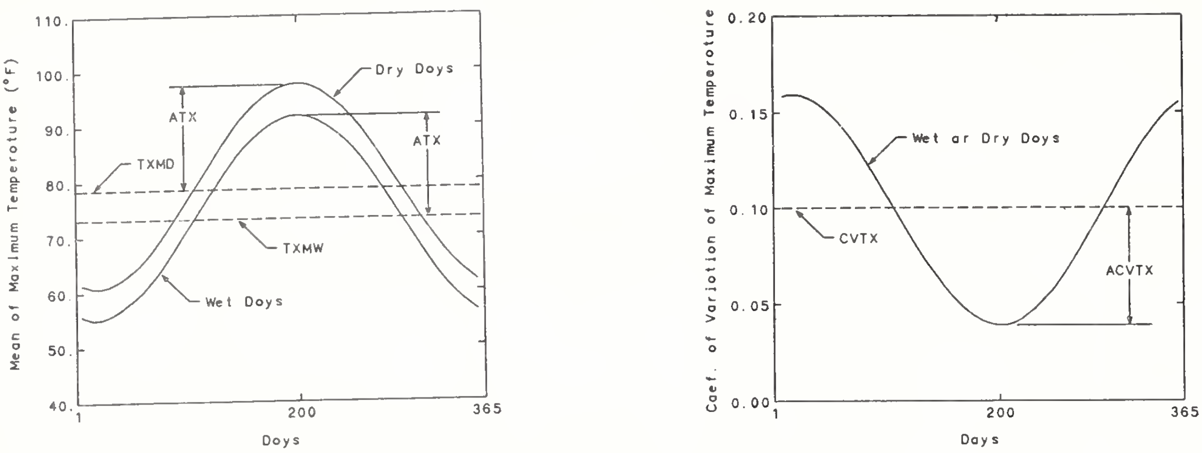
The s_j values may be calculated by:

$$s_j = c_v \bar{v}_j \tag{19}$$

The $\bar{v}_j$ and s_j values are used with the gamma-generation procedure (Haan 1977) to generate daily wind speeds. Wind speeds are then converted to daily wind run.

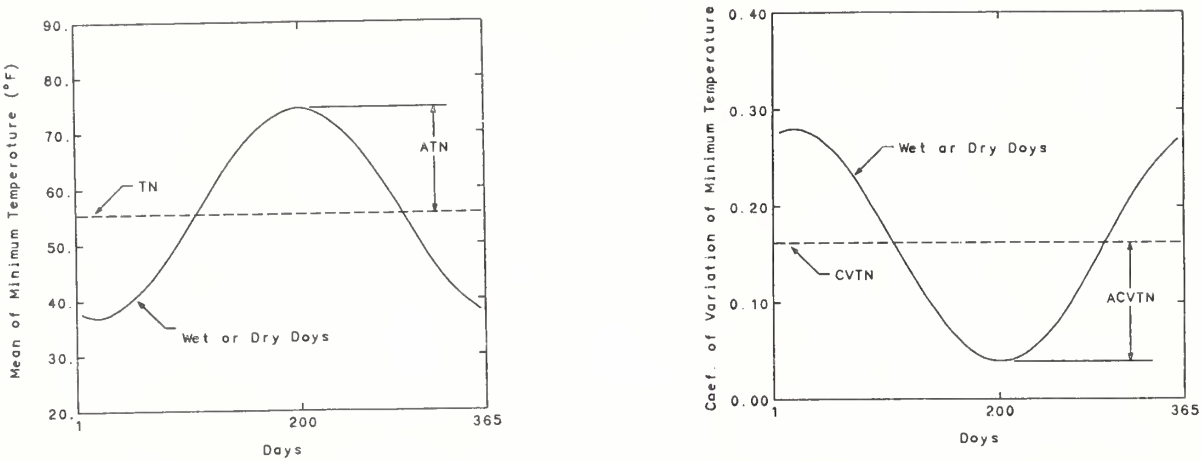
The GENPAR Program

If users need to generate weather data for a location outside the 48 States or if they need to develop generation parameters from actual data from a specific location, the GENPAR program may be used. The GENPAR program reads daily values of p, t_{max}, t_{min}, and r and writes the generation parameters which are required by CLIMGN. The number of years of weather data required to develop parameters which are representative of a particular location varies with the climate. In



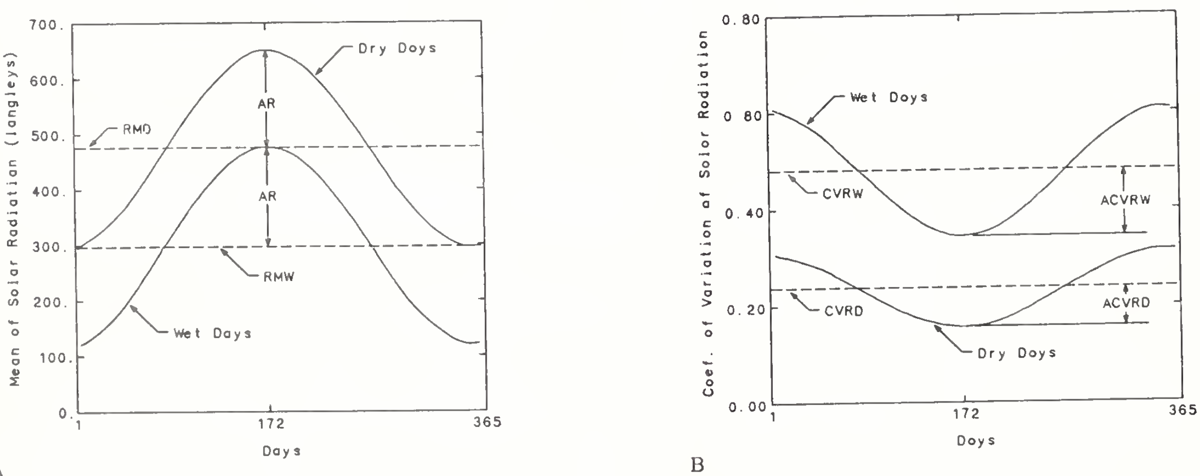
A B

Figure 2.2
Definition of generation parameters for maximum temperature.



A B

Figure 2.3
Definition of generation parameters for minimum temperature.



A B

Figure 2.4
Definition of generation parameters for solar radiation.

general, at least 20 years of precipitation data and 10 years of temperature and radiation data are required. Longer records of precipitation may be required for arid locations.

Solar Radiation Correction for Sloping Terrain

Within the SPUR program, subprogram SOLADJ is used to provide a factor for adjusting the radiation values generated by the climate model for a horizontal surface to the actual slope and aspect conditions existing at the site being simulated. The procedure uses the method outlined by Lee (1963) to calculate the potential insolation on both a horizontal and an inclined surface. The ratio between them is the adjustment factor used by the SPUR model. Since potential insolation neglects the effect of the atmosphere, it is a function only of the angle between the surface and the rays of the sun which, in turn, is a function of the site location, surface geometry, date, and time of day which are respectively characterized by the latitude and longitude of the site, slope and aspect of the surface, declination, and hour angle of the sun. The classic work of Milankovitch (1930) forms the basis for the equations used to calculate the solar radiation received at a point on a horizontal surface at a given latitude and point in time. The theory of "equivalent slope" is used to obtain values for nonhorizontal surfaces. The specific equations used in this calculation are those proposed by Kimball (1919) as corrected by Okanoue (1957).

The total solar radiation on a horizontal surface, neglecting the atmosphere, is given by:

$$I_q = \frac{I_o}{e^2}\int_{t_1}^{t_2} \cos(z)\, dt \tag{20}$$

where I_q is the solar radiation in gm cal cm^{-2} (langleys); I_o is the solar constant, 2.00 langleys/minute; e^2 is the radius vector of the earth; t_1 is the time of sunrise, hours from true solar noon (-); t_2 is the time of sunset, hours from true solar noon (+); and cos z is the sun's zenith distance given by:

$$\cos(z) = \cos(L)\cos(\delta)\cos(wt) + \sin(L)\sin(\delta) \tag{21}$$

where L is the latitude of the site, δ is the declination of the sun for that date, and w is the angular velocity of the earth's rotation, 15 degrees/hour.

The variable, I_q, is obtained by substituting equation 21 into equation 20 and integrating with respect to time. This yields:

$$I_q = 60\,\frac{I_o}{e^2}\Big[(t_2 - t_1)\sin(L)\sin(\delta) + \frac{B}{w}\cos(L)\cos(\delta)\Big] \tag{22}$$

$$B = \sin(wt_2) - \sin(wt_1)$$

The declination, δ, is a function of the date and is given by the equation proposed by Tscheschke and Gilley (1978):

$$\delta = 23.45\cos\left(360\,\frac{\text{DAY} - 172}{365.25}\right) \tag{23}$$

where δ is the declination of the sun in degrees, and DAY is the day of the year measured from January 1.

The Milankovitch equations were modified by Okanoue (1957) to allow for similar solutions for surfaces which are not horizontal. For this case, the potential insolation is given by:

$$I_a = 60\,I_p\Big[(t_2 - t_1)\,A\sin(\delta) + \frac{C}{w}(1 - A^2)^{\frac{1}{2}}\cos(\delta)\Big] \tag{24}$$

where I_a is the solar radiation on the inclined surface in langleys, A is:

$$A = \sin(S)\cos(\theta)\cos(L) + \cos(S)\sin(L)$$

and C is:

$$C = \sin(wt_2 + \alpha) - \sin(wt_1 + \alpha)$$

$$\alpha = \tan^{-1}\left[\frac{\sin(S)\sin(\theta)}{\cos(S)\cos(L) - \cos(\theta)\sin(S)\sin(L)}\right]$$

and:

$$I_p = \frac{I_o}{e^2} = 2.00 + 0.07\cos\left(360\,\frac{\text{DAY}}{365.25}\right)$$

where A is the sine of the latitude of the horizontal surface equivalent to the inclined surface at the evaluation site, S is the slope in degrees, θ is the aspect in degrees clockwise from north, and α is the difference in longitude between the location of a given slope and that of an equivalent horizontal surface.

The time of sunrise, t_1, and sunset, t_2, must be calculated to evaluate equations 22 and 24. Utilizing the fact that the zenith distance is zero at sunrise and sunset, their respective times may be calculated by setting equation 21 to zero and solving for t. This results in:

$$t = \pm\frac{1}{w}\cos^{-1}[-\tan(L)\tan(\delta)] \tag{25}$$

measured from solar noon. The time of sunrise and sunset for the equivalent horizontal surface is calculated in a similar manner with the equivalent latitude, L_e, replacing L in equation 25.

Thus:

$$L_e = \sin^{-1}(A)$$

$$t_e = \pm \frac{1}{w} \cos^{-1}[-\tan(L_e)\tan(\delta)] \qquad (26)$$

The times of sunrise and sunset at the actual site are obtained by subtracting the time shift due to the longitudinal displacement of the equivalent surface and are given by:

$$t_1 = -t_e - \frac{\alpha}{w} \qquad (27)$$

$$t_2 = t_e - \frac{\alpha}{w} \qquad (28)$$

and are subject to the constraint that the absolute values of t_1 and t_2 must be less than the absolute value of t from equation 25.

The index returned by subroutine SOLADJ is the ratio of I_a to I_q for the site being simulated.

MODEL TESTS

The CLIMGN model has been subjected to extensive testing. Richardson and Wright (1984) ran the model for six locations (Columbia, MO, Boise, ID, Fort Worth, TX, Miami, FL, Phoenix, AZ, and Boston, MA) and compared the results with actual weather data. They used the same rainfall, temperature and solar radiation parameters as those presented in table 10.1 and figures 10.1 through 10.12 of chapter 10, Part II. A 30-year sample of weather data was generated for each location without correcting precipitation and temperature based on actual monthly means.

Several statistics were selected for comparing the generated weather data with observed data. The following statistics were compared for each month and for the year:

1. Mean precipitation amount,
2. Mean number of wet days ($p > 0.01$ in),
3. Mean run of wet days (maximum length of consecutive wet days),
4. Mean number of days with $p > 2.0$ in,
5. Mean daily solar radiation,
6. Mean daily maximum temperature,
7. Mean daily minimum temperature,
8. Mean monthly and annual maximum temperature,
9. Mean monthly and annual minimum temperature,
10. Mean number of days with $t_{max} > 95$ °F, and
11. Mean number of days with $t_{min} < 32$ °F.

The Markov chain-gamma model that was used for generating daily precipitation amounts gave results that compared well with the observed data. The precipitation amounts and the seasonal distribution of precipitation were accurately represented in the generated data. There were no significant differences in the mean monthly or annual precipitation amounts for any of the six locations. The mean number of wet days per month was also accurately simulated at all six locations. The persistence of wet days, as indicated by the maximum length of consecutive wet days for each month and the frequency of occurrence of daily precipitation in excess of 2.0 in also compared favorably with the observed data.

The mean daily solar radiation generated with CLIMGN was not significantly different from the observed data for any month at any of the six locations.

The generation procedure for daily maximum and minimum temperatures also produced results that are good representations of the observed data. Mean daily maximum and mean daily minimum temperatures by month were significantly different in only 24 of the 156 cases. Most of the differences were due to the actual data not having a simple sinusodial shape as assumed in the model (fig. 2.2). Use of the temperature correction described previously can correct this problem.

The statistics that reflect temperature extremes did not compare as well with the observed as did the other statistics. This result could be expected because the extremes were not as directly related to the generation procedure as were the mean monthly temperatures. In general, however, the temperature extremes are adequate for most applications.

The precipitation and temperature correction procedures offer an opportunity to make adjustments in the generation procedure when the parameters from table 10.1 and figures 10.1 through 10.12 of chapter 10 in Part II are not adequate because of some physical effect such as topography or a more precise definition of precipitation and/or temperature is needed. As an example of the application of the correction procedure, a 30-year record of weather data was generated for a site on Reynolds Mountain (obtained by USDA-ARS, NW Watershed Research Center) southwest of Boise, ID. Boise was the nearest location represented in table 10.1 from which precipitation parameters could be obtained. The elevation at the Reynolds Mountain site is 7,100 feet (precipitation measured at 7,100 ft, temperature at 6,880 ft), while the elevation at Boise is only 2,840 feet. The precipitation regime on Reynolds Mountain is much different from that in Boise because of the elevation difference and related factors. Similarly, temperatures are much less at the Reynolds Mountain site than would be generated using the parameters from figures 10.1 through 10.12 of Part II since the parameters were developed for sites at lower elevations such as Boise. To adjust these differences, the precipitation and temperature correction options

were used. The mean monthly precipitation, maximum temperature, and minimum temperature were calculated from actual data from Reynolds Mountain. These means were input to the CLIMGN program along with the generation parameters for Boise obtained from table 10.1 and figures 10.1 through 10.12 from Part II.

The results of the generation are shown in table 2.6. The mean monthly precipitation amounts from the generated data are an excellent representation of the observed data. However, the number of wet days which are generated are less than the observed because only the rainfall amounts are changed with the correction procedure. The daily maximum and minimum temperatures generated using the correction procedure also compare closely with the observed data for Reynolds Mountain and are much less than would be generated without the correction procedure.

The generated wind speed was compared with the observed wind data at Boise shown in table 2.7. The generated mean wind speed for all but three months was within 10 percent and all months were within 20 percent. The generated average annual wind speed was within 10 percent of the measured value.

DISCUSSION

The CLIMGN model is designed for use in generating daily values of precipitation, maximum temperature, minimum temperature, solar radiation, and wind run that are representative of the weather at a specific site. The generation procedure is designed to preserve the serial dependence (persistence) of each variable and the dependence among the precipitation, maximum and minimum temperature, and solar radiation variables, as well as the seasonal characteristics of the variables. The basic structure of the model is simple and many assumptions are made to enable general application of the model. Some assumptions may be questionable from a physical standpoint but are reasonable and expedient from an application's standpoint and do not adversely affect the usefulness of the data generated.

Four major options that use climatic records are available with the SPUR computer program. The user may choose to (1) use recorded climatic records for all five variables (daily precipitation, maximum and minimum temperatures, solar radiation, and wind run), (2) generate daily values of all five variables, (3) use actual precipitation data and generate the other four variables, or (4) use climatic records for precipitation, maximum and minimum temperature, and solar radiation and generate wind run. The last three options require the use of of a climate generator like CLIMGN.

In addition to these four major options, the user may choose to apply correction factors to precipitation and/or temperature based on actual mean monthly values and to correct solar radiation for sloping terrain. This is done by supplying the SPUR program with the appropriate initial conditions.

Table 2.6
Observed and generated weather data for Reynolds Mountain using the precipitation and temperature correction procedure, by month

WEATHER DATA	MONTH												ANNUAL
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
PRECIPITATION													
AMOUNT (IN)													
OBSERVED MEAN	8.03	4.68	4.60	3.87	2.62	2.30	0.67	1.17	1.31	2.48	5.52	6.09	43.34
GENERATED MEAN	7.66	5.83	4.87	3.77	2.70	2.06	0.69	1.65	0.98	2.29	5.58	6.15	44.25
NO. OF WET DAYS													
OBSERVED MEAN	16.8	13.3	15.1	12.9	10.6	10.0	4.7	6.0	5.4	8.9	13.3	16.6	133.5
GENERATED MEAN	12.5*	12.2	9.2*	8.1*	8.6	6.3*	1.8*	3.3*	3.3*	6.1*	8.9*	12.3*	92.6*
TEMPERATURE													
DAILY MAXIMUM (°F)													
OBSERVED MEAN	27.2	31.0	33.0	38.7	50.8	61.8	72.1	70.1	60.9	48.8	36.0	29.3	46.6
GENERATED MEAN	27.2	30.8	32.9	38.8	50.8	61.9	71.5	69.5	61.1	48.9	35.8	30.2	46.7
DAILY MINIMUM (°F)													
OBSERVED MEAN	17.8	21.4	21.2	24.7	34.7	44.0	53.4	52.1	44.0	34.7	25.3	19.5	32.7
GENERATED MEAN	17.1	21.6	21.0	24.2	34.8	44.3	53.1	52.4	44.6	34.5	25.0	20.2	32.8

* Generated values are significantly different from observed values at 5 percent level.

Table 2.7
Mean daily wind speed from observed data and data generated with CLIMGN, Boise, ID

Month	Wind speed (m/h) Observed	Generated
Jan	8.9	9.1
Feb	8.9	10.5
Mar	10.0	10.9
Apr	11.2	10.1
May	9.5	10.8
Jun	9.2	8.7
Jul	8.7	8.6
Aug	8.6	8.1
Sep	8.7	8.4
Oct	8.2	9.3
Nov	9.1	8.7
Dec	9.5	9.0
Average	9.2	9.3

To apply CLIMGN to a particular site requires defining 48 precipitation parameters, 12 temperature and radiation parameters, and 14 wind speed parameters. The precipitation parameters have been defined for 139 locations in the United States (see part II, chapter 10). The temperature and radiation parameters have been mapped and are given in figures 10.1 through 10.12 of chapter 10, part II. The wind run parameters are in the Climatic Atlas of the United States (U.S. Department of Commerce 1968).

The radiation-adjustment-factor computation is part of the SPUR code. The information for this adjustment is read by SPUR from the simulation control, hydrology, and soils data file (see table 2.3, chapter 10, part II). These data are month, day, and year, as well as values for the site latitude in degrees north, aspect in degrees clockwise from north, and the percent slope.

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3. HYDROLOGY COMPONENT: UPLAND PHASES

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INTRODUCTION

The hydrology component of the model is designed to use inputs from the climate component and produce outputs for use unto its own (for example, runoff and sediment yield) or inputs for other components of the SPUR model (for example, estimates of available soil moisture for forage production). The hydrology component is divided into three parts: an upland phase, a snowmelt phase, and a channel phase. The upland phase is discussed in this chapter.

In streams draining rangeland areas of the Western United States, extreme spatial and temporal variability in physiographic and climatic conditions require that a hydrologic model consider such conditions. For example, an individual storm event occurring as rain at low elevations and snow at high elevations is a possibility. Airmass thunderstorms dominating the rainfall-runoff process in the semiarid Southwest have extreme variations in precipitation depth in short distances (1 in/mi is not rare).

A hydrologic model component should be capable of simulating the effects of management changes on streamflow for streams that may have influent or effluent characteristics, have flow conditions that are subcritical or supercritical, and have a wide variety of slopes up to steep, rocky, pool-riffle systems.

The objectives of the upland phase of the hydrology model are to (1) be capable of predicting changes in water quantity and quality resulting from management changes; (2) be physically based, so that model parameters can be evaluated from available data for ungaged areas; (3) have sufficient detail to allow simulation on subdivided watersheds to coincide more or less with ranch and pasture boundaries; (4) be computationally efficient to enable long-term simulation for frequency analyses; (5) be capable of providing input to other SPUR model components, such as soil moisture for plant-forage-yield; and (6) be used for environmental impact analysis, nonpoint pollution assessment, and other types of resource utilization and environmental-protection-problem solutions.

Although these objectives may seem overly ambitious, significant improvements have been made in water resource models in recent years (Crawford and Donigian 1976; Williams and LaSeur 1976; Beasley et al. 1977; Simons et al. 1977; Knisel 1980a, 1980b) which facilitate such a development.

The upland phases of the hydrology model for SPUR draw heavily from a model called SWRRB (Williams et al. 1985), which has been modified and improved to consider the essential features known to affect the hydrologic response from rangelands. The SWRRB model includes the major processes of surface runoff, percolation, return flow, evapotranspiration, pond and reservoir storage, and erosion and sedimentation. The well known curve number technique (USDA 1972) is used to predict surface runoff for any given precipitation event because (1) many years of use have given confidence in its validity; (2) it relates runoff, soil type, vegetation, land use and management; and (3) it is computationally efficient. The use of rainfall data for short time increments (minutes and/or hours), which is required with infiltration equations to compute precipitation excess, is not generally available for most areas of the United States, and especially not on the rangelands with the orographic precipitation effects, sparsity of recording rain gages, etc. Finally, daily rainfall estimates are computationally more efficient than similar operations with shorter time increments.

MODEL DESCRIPTION

Water Balance

The SPUR model maintains a continuous water balance on a daily computational basis using the equation:

$$SW = SW_o + P - Q - ET - PL - QR \qquad (1)$$

where:

- SW = current soil water content (in),
- SW_o = initial soil water content (in),
- P = cumulative rainfall (in),
- Q = cumulative amount of surface runoff (in),
- ET = cumulative amount of evapotranspiration (in),
- PL = cumulative amount of percolation loss to ground water storage (in),
- QR = cumulative amount of return flow (in).

In maintaining the continuous water balance, complex watersheds are subdivided to reflect such diverse factors as different vegetation or soils, topography, and stream morphology. In other words, runoff is computed for each subarea, and the water is routed to the outlet of the basin to obtain the total runoff. This accounting allows changing management practices of only part of the area and should improve the model's accuracy, yet, provide a more detailed physical preservation of the watershed details.

Soil/Plant Water Relationship

The plant component of SPUR requires soil water tensions for the 6 in (15 cm) depth, and for the wettest layer in the root zone to simulate plant growth (chapter 6). Several relationships are available which describe the soil water characteristic curve (Brooks and Corey 1966; van Genuchten 1980). The functional form was deemed

necessary for SPUR, because range vegetation can operate at tensions significantly greater than the 15-bar lower limit used in agronomic situations, so an extrapolation to some lower limit had to be conducted. Also, limited information available for soils found on range sites stipulated that requiring more data than is already in the model, which is porosity, 1/3-bar water content, and 15-bar water content, would limit potential application of the model. Therefore, the simple power function model proposed by Campbell (1974) was used because it has only two parameters.

Campbell's equation is:

$$h_s = h_a \left(\frac{T}{T_s}\right)^b \tag{2}$$

where:

h_s = soil water tension (cm),
h_a = air entry tension (cm),
T = volumetric soil water content,
T_s = saturated volumetric soil water content, and
b = parameter.

By using a logarithmic transformation, equation 1 can be rewritten to solve for h_a and b using the porosity, 1/3-bar and 15-bar water contents. The solution for b, assuming 1020 cm/bar, is:

$$b = \frac{\ln(340) - \ln(15300)}{\ln(S_3) - \ln(S_{15})} \tag{3}$$

where:

S_3 = T(at 1/3 bar)/porosity, and
S_{15} = T(at 15 bars)/porosity.

The value for h_a is found by solving equation 2 using the 1/3-bar tension and water content. These parameters are computed for each layer.

The 15-bar water content has traditionally been set as the lower bound of available water for agronomic crops. Rangeland vegetation, particularly perennials and shrubs, are capable of functioning at tensions much lower than 15 bars. There are essentially no soils data available at this tension, so equation 2 was extrapolated to provide the 50-bar volumetric water content. Users should be cautioned that these values are an extrapolation of the data. The definition of available water in the model is changed to reflect the 50-bar water content (see following section).

Soil-Layer Water Storage

The soil in each subarea of the watershed is divided into layers (user-specified number of layers (up to eight) and layer thickness for each subarea). Water balance is done on a daily basis using rainfall excess, evapotranspiration, percolation, and return flow, as described in equation 1. Total storage, field capacity, and initial water storage in the various layers are expressed in terms of plant available water and are computed from input parameters as follows:

$$UL_i = (SM0_i - SM50_i)\ THK_i \tag{4}$$

$$FC_i = (SM3_i - SM50_i)\ THK_i \tag{5}$$

$$SW_{oi} = FC_i\ STF \tag{6}$$

where:

UL_i = upper limit of water storage in layer i (in),
FC_i = field capacity in layer i (in),
SW_{oi} = initial soil water in layer i (in),
$SM0_i$ = soil porosity for layer i (in/in),
$SM3_i$ = 1/3-bar water content for layer i (in/in),
$SM50_i$ = 50-bar water content for layer i (in/in),
THK_i = soil layer thickness for layer i (in), and
STF = initial soil water content as a fraction of field capacity for the entire soil profile.

Runoff

The traditional three antecedent moisture levels (I - dry, II - normal, III - wet), as used by the Soil Conservation Service (SCS), have been modified in the model by allowing soil moisture to be updated daily and by computing daily curve numbers based on soil-water storage, rather than using the three curve numbers associated with their moisture classes. Thus, each day has a curve number (Williams and LaSeur 1976), and the soil moisture changes between runoff events with estimates of evapotranspiration and percolation using routines very similar to those used in CREAMS (Knisel 1980b). From the curve number method, surface runoff is estimated on a daily basis from:

$$Q = \frac{(P - I_a)^2}{P + s - I_a} = \frac{(P - 0.2s)^2}{P - 0.8s} \tag{7}$$

where:

Q = daily runoff (in),
P = daily rainfall (in),
s = a retention parameter (in), and
I_a = 0.2s = initial abstraction.

The maximum value, s_{mx}, for the retention parameter, s, is computed with the following SCS curve number relationship (USDA 1972):

$$s_{mx} = \frac{1000}{CN_I} - 10 \tag{8}$$

where CN_I is the dry-antecedent-moisture-condition curve number. If handbook curve numbers are available for the normal moisture condition, CN_{II},

the following polynomial may be used to estimate CN_I:

$$CN_I = -16.91 + 1.348\ CN_{II} - 0.01379\ CN_{II}^2 + 0.0001177\ CN_{II}^3 \quad (9)$$

The soil retention parameter is computed daily as a weighted average of the unused storage in the various soil layers scale from zero to s_{mx}. It is:

$$s = s_{mx} \sum_{i=1}^{n} (W_i \frac{UL_i - SW_i}{UL_i}) \quad (10)$$

where:

n = number of soil layers,
SW_i = current water storage in layer i (updated daily) (in), and
W_i = weighting factor.

The weighting factors decrease exponentially to give greater dependence of s on the upper soil layers, so:

$$W_i = o\ e^{-4.16\ d_i} \quad (11)$$

where:

d_i = (depth to bottom of layer i)/(depth to bottom of last layer), and

a = constant adjusted so $\sum_{i=1}^{n} W_i = 1$

Peak Flow Calculation

Peak discharge for daily runoff events is calculated using some relationships discussed in the channel routing process (chapter 5):

$$Q_p = C_5 \frac{Q}{D} \quad (12)$$

where:

Q_p = peak flow rate (in/h),
Q = daily runoff volume (in),
D = duration of runoff (h), and
C_5 = a constant.

Runoff duration (D is in h) is obtained from:

$$D = C_1 A^{C_2} \quad (13)$$

where:

A = watershed area (acres); and C_1 and C_2 are constants.

Combining equations and converting units gives:

$$Q_p = 1.00833 \frac{C_5}{C_1} Q\ A^{-C_2} \quad (14)$$

where the constant (1.00833) allows conversion to give Q_p in cubic feet per second. The constants C_1, C_2, and C_5 are data input to the program.

Percolation

The percolation component of SPUR uses a storage routing model combined with a crack-flow model to predict flow through the root zone. These models are similar to those used in CREAMS (Knisel 1980b) and SWRRB. Water moving below the root zone becomes ground water, or appears as return flow that is routed into the channel network.

In the following, $PL1_i$ is percolation flow out of the bottom of layer i from the storage routing model. The variable $PL2_i$ is the crack flow out of the same layer. The variable PL_i is equal to $PL1_i$ plus $PL2_i$ and is the total flow out of layer i (ignoring return flow). The variable PL_0 is computed as being equal to precipitation minus rainfall excess; it is the amount of water flowing into the first layer.

Flow through a soil layer may be restricted by a lower layer which is saturated or nearly saturated. The variable PL_i, as subsequently computed, may exceed the projected available storage in the next layer (UL_{i+1} - SW_{i+1} + projected evapotranspiration losses from layer i + 1), in which case, PL_i is set to this projected value. There is no "succeeding" layer to the bottom layer. Crack-flow computations use bottom layer values where the bottom layer needs succeeding layer values. The value of PL2 is not limited by the succeeding layer.

Storage Routing

The storage routing model uses an exponential function with the percolation computed by subtracting the soil water in excess of field capacity at the end of the day from that at the beginning of the day, or:

$$PL1_i = \begin{cases} (SW_i - FC_i)(1 - e^{-\frac{\Delta t}{T_i}}) & SW_i > FC_i \\ 0 & SW_i \leqq FC_i \end{cases} \quad (15)$$

where:

$PL1_i$ = amount of percolate (in),
SW_i = the soil water content at the beginning of the day for layer i (in)
Δt = time interval (24 h),
T_i = travel time through a particular layer (h),
FC_i = the field capacity water content for layer i, (in), and
i = soil layer number increasing with depth.

The travel time through each soil layer is computed with the linear storage equation:

$$T_i = \frac{SW_i - FC_i}{H_i} \quad (16)$$

where:

H_i = the hydraulic conductivity of layer i (in/h).

Hydraulic conductivity is varied from the specified saturated conductivity value by:

$$H_i = SC_i \left(\frac{SW_i}{UL_i}\right)^{\beta_i} \tag{17}$$

where:

SC_i = saturated conductivity for layer i (in/hr), and
β_i = parameter that causes H_i 0.0022 SC_i as SW_i FC_i.

The equation for estimating β_i is:

$$\beta_i = \frac{-2.655}{\log\left(\frac{FC_i}{UL_i}\right)} \tag{18}$$

where the constant (-2.655) assures that $H_i = 0.0022\ SC_i$ at field capacity.

Crack Flow

The crack-flow routine is used in the model to allow percolation of infiltrated precipitation, even though the soil water content may be less than field capacity. Given a dry soil with cracks, infiltration can move through the cracks of a layer without becoming part of the soil water in the layer, while the portion that becomes part of a layer's stored water cannot percolate by the storage-routing model until the storage exceeds field capacity.

Crack-flow percolation uses the equation:

$$PL2_i = d_c\, PL_{i-1} \left(1 - \frac{SW_{i+1}}{UL_{i+1}}\right)^2 \tag{19}$$

where d_c is a soil parameter that expresses degree of cracking. Crack flow occurs only on days when water enters the layer (PL_{i-1}) and is greatest when the next lower layer is dry.

Since the daily time increment is relatively long for routing the flow through soils, it is desirable to route the water in volume increments. The increments to be routed are variable and are a function of the difference between the UL_i minus FC_i and the total amount to be routed. By dividing the layer inflow into several "slugs," each slug may be routed through the layer, thus allowing SW_i to be updated during the calculation.

Return Flow

Return flow is calculated as coming from the bottom soil layer, n. The return-flow function used for SWRRB is also used in SPUR (note the similarity to equation 15). Thus:

$$QR = (SW_n - FC_n)(1 - e^{\frac{1}{T_R}}) \tag{20}$$

where:

QR = return flow (in),
T_R = return-flow travel time (days), and
n = last soil layer.

Return-flow time, T_R, is the time required for subsurface flow from the centroid of the basin to the basin outlet. The value of T_R is input for each subarea by the SPUR user instead of being calculated from soil hydraulic properties. Experienced hydrologists familiar with the base-flow characteristics of watersheds within a region should have little problem in assigning reasonable values to T_R.

Evapotranspiration

The evapotranspiration (ET) component in SPUR is the same as that used in CREAMS and SWRRB and is based on work by Ritchie (1972). Potential evaporation is computed with the equation:

$$E_o = \frac{0.0504\, H_o \Delta}{\gamma + \Delta} \tag{21}$$

where:

E_o = potential evaporation (in),
Δ = slope of the saturation-vapor-pressure curve at the mean air temperature,
H_o = net solar radiation (ly), and
γ = a psychrometric constant,

and Δ is computed with the equation:

$$\Delta = \frac{5304}{T_k^2} e^{(21.255 - \frac{5304}{T_k})} \tag{22}$$

where:

T_k = daily temperature (degrees Kelvin).

The variable H_o is calculated with the equation:

$$H_o = \frac{(1 - \lambda)\, R}{58.3} \tag{23}$$

where:

R = daily solar radiation (ly) and
λ = albedo.

Soil Evaporation

The model computes soil evaporation and plant transpiration separately. Potential soil evaporation is computed with the equation:

$$E_{so} = \min \begin{cases} E_o e^{-0.4\, LAI} \\ E_o GR \end{cases} \tag{24}$$

where:

E_{so} = potential evaporation at the soil surface (in),
LAI = leaf area index defined as the area of plant leaves relative to the soil surface (in/in), and
GR = mulch (residue) cover factor. (We suggest using a value of 0.5 for most range plant communities, and 1.0 for bare soil.)

Actual soil evaporation (E_s) is computed in two stages based on the soil moisture status in the upper soil profile. In stage 1, soil evaporation is limited only by the energy available at the surface and, thus, is equal to the potential (eq. 24). When the accumulated soil evaporation exceeds the first-stage upper limit, the stage-2 evaporation begins (the reader is referred to Ritchie (1972) for additional explanation of the procedure). The first-stage upper limit is estimated from:

$$U = 1.38\,(\alpha - 0.118)^{0.42} \qquad (25)$$

where:

U = stage-1 upper limit (in) and
α = soil evaporation parameter dependent on soil-water transmission characteristics (ranges from 0.13 to 0.22 in/day$^{1/2}$).

Ritchie (1972) suggests using α = 0.14 for clay soils, 0.18 for loamy soils, and 0.13 for sandy soils. Similar values were obtained for data from Jackson et al. (1976). A wider distribution of values for most soil textural classes is given by Lane and Stone (1983).

Stage-2 soil evaporation is predicted by:

$$E_s = \alpha\,[t^{\frac{1}{2}} - (t-1)^{\frac{1}{2}}] \qquad (26)$$

where:

E_s = soil evaporation for day t (in) and
t = days since stage-2 evaporation began.

Plant Transpiration

Potential transpiration (E_{po}) from plants is computed with the equations:

$$E_{po} = \frac{E_o\,LAI}{3} \qquad 0 \leqq LAI \leqq 3 \qquad (27)$$

$$E_{po} = E_o - E_s \qquad LAI > 3 \qquad (28)$$

(If $E_{po} + E_s > E_o$, E_s is reduced so $E_{po} + E_s = E_o$.) Because the LAI is generally considerably less than three in rangeland plant communities that SPUR is intended to consider, equation 27 will be used most of the time. If soil water is limited, plant transpiration is reduced with the equation:

$$E_p = \frac{E_{po}\,SW}{0.25\,FC} \qquad SW \leqq 0.25\,FC \qquad (29)$$

where:

E_p = plant transpiration reduced by limited soil moisture (in) and
SW = current soil water in the root zone (in).

(If SW > 0.25 (FC), $E_p = E_{po}$, and if $E_p + E_s$ exceeds available water, E_s is reduced so $E_p + E_s$ = available water.)

Evapotranspiration (ET), then, is the sum of plant transpiration (eq. 27, 28 or 29) plus soil evaporation (eq. 25 or 26), and cannot exceed available soil water.

Distribution of ET in the Soil Profile

Soil-water evaporation is removed uniformly from the soil profile down to a maximum depth (ESD). The variable ESD is set in the SPUR code. If the soil profile does not contain sufficient water to meet soil-water evaporation demand, the actual amount of evaporation is reduced accordingly.

Transpiration is initially distributed through the soil layers by the following equation:

$$v = v_o\, e^{-v_1 D} \qquad (30)$$

where:

v = water-use rate by crop at depth D (in/day),
v_o = water-use rate at the surface (in/day),
v_1 = 3.065, and
D = soil depth/depth to bottom of last soil layer with roots.

The total water use within any depth can be computed by integrating equation 30. The value of v_o is determined for the root depth each day, and the water use in each soil layer is computed with the equations:

$$v_o = \frac{v_1\,ET}{1 - e^{-v_1}} \qquad (31)$$

$$UW_i = \frac{v_o}{v_1}\left(e^{-v_1 D_{i-1}} - e^{-v_1 D_i}\right) \qquad (32)$$

where:

UW_i = water use in layer i (in), and

D_{i-1} and D_i = the fractional depths at the top and bottom of layer i.

When calculating actual uptake, transmission demand for a layer that cannot be satisfied by the available water in that layer is added to the

demand of the next layer. This process is continued until the transpiration demand is satisfied or the bottom of the root zone is reached.

(The UW_i vector contains the initial estimates of ET which are to be subtracted from the various soil layers. If a layer has insufficient water, the excess ET is taken out of the first layer containing available water and having roots present.)

Water Balance for Ponds

Water for grazing animals in rangeland watersheds is often supplied by small earth dams, which create small ponds. These ponds can hold a considerable part of the runoff from the contributing watershed, depending upon how full the pond is when runoff begins. In addition, the retention of water in such ponds can result in a significant delay or reduction in the downstream runoff and a distortion of the time/flow-rate relationship. The SPUR model uses a component of SWRRB that was designed to account for the effects of farm/ranch ponds on water yield. The water balance equation is:

$$VM = VM_o + QI - QO - EV - SP \qquad (33)$$

where:

- VM = volume of water stored in pond at end of day (acre-ft),
- VM_o = volume of water in pond at beginning of day (acre-ft),
- QI = inflow to the pond during the day (acre-ft),
- QO = outflow from the pond during the day (acre-ft),
- EV = evaporation from pond (acre-ft), and
- SP = seepage from pond (acre-ft).

(The amount of water consumed by grazing animals is assumed to be negligible compared with seepage and evaporation losses.)

Inflow, QI, is considered to be surface runoff from the watershed area draining into the pond plus precipitation on the pond's water surface. Outflow from the pond occurs from either an emergency spillway or a principal spillway and occurs when the permanent pool storage is exceeded. Evaporation from the pond is computed with the equation:

$$EV = \frac{1}{12} \alpha E_o SA \qquad (34)$$

where:

- α = evaporation coefficient (≃0.6), and
- SA = surface area of the pond (acres).

Seepage from the pond is computed with the equation:

$$SP = 2\ SC\ SA \qquad (35)$$

where:

- SC = saturated-soil conductivity of the pond bottom (in/h).

No effort was made to make SC vary with water depth and other factors, like soil stratification or sediment distribution, in the pond. These modifications were felt to be unwarranted because of the need for additional detailed user-supplied information to implement them.

Since pond surface area is required for computing evaporation (eq. 34) and seepage (eq. 35), a relationship between pond volume and surface area is necessary. Data from many stock ponds and small reservoirs in Texas and Oklahoma (USDA 1957) indicate that surface area can be calculated with the equation:

$$SA = SA_{max} \left[\frac{VM}{VM_{max}} \right]^{\delta} \qquad (36)$$

where:

- δ = a parameter determined to be 0.9,
- VM_{max} = maximum pond volume (acre-ft), and
- SA_{max} = maximum pond surface area (acre).

Other research by Hanson et al. (1975) indicated that, in Montana and South Dakota, the exponent should be about 0.7.

Sediment Yield

Estimating soil loss from the upland areas of rangelands is difficult (Renard 1980) because most of the technology currently used was developed for cultivated cropland areas. The Universal Soil Loss Equation (USLE) (Wischmeier and Smith 1978) and the modification to this equation (MUSLE) (Williams and Berndt 1977) are used in the basin-scale version of SPUR. The equation used is:

$$Y = \eta (Q\ Q_p)^{0.56}\ K\ C\ P\ LS \qquad (37)$$

where:

- Y = sediment yield from upland area (tons/acre),
- η = coefficient = 95,
- Q = upland runoff volume (in),
- Q_p = peak-flow rate (ft^3/s),
- K = soil erodibility factor,
- C = cover/management factor,
- P = erosion control practice factor, and
- LS = slope length and steepness factor.

Determining the LS factor in this equation is critical to calculating sediment yield. The model elements must be carefully selected to describe prototype configuration. As the model is used to describe larger and larger elements, some detail is lost. Thus, the way the LS term is evaluated may change with the size of the area to be simulated. The average land slope of any subarea or subwatershed can be estimated by field measurements or by measurements from a topographic

map with the Grid-Contour Method (Williams and Berndt 1976) using the equations:

$$S_d = N_d \frac{H}{D_d} \tag{38}$$

$$S = [S_l^2 + S_w^2]^{\frac{1}{2}} \tag{39}$$

where:

- S_d = slope in one grid direction,
- S = average land slope of a subarea or subwatershed,
- N_d = total number of contour crossings from all grid lines in direction d,
- H = contour interval,
- D_d = total length of all grid lines within the subarea in direction d,
- S_l = slope in the length grid direction obtained from equation 38 and,
- S_w = slope in the width direction obtained from equation 38.

The average slope length can be estimated for each subarea or subwatershed by field measurements, or with the Contour-Extreme Point Method (Williams and Berndt 1976) by:

$$L = \frac{LC}{2EP} \tag{40}$$

where:

- EP = number of extreme points (channel crossings) on the contours of a topographic map,
- LC = total length of all contours within the subarea or subwatershed, and,
- L = average slope length (ft).

The LS factor is computed with the equation:

$$LS = \left[\frac{L}{72.6}\right]^M [65.41 \sin^2(\theta) + 4.56 \sin(\theta) + 0.065] \tag{41}$$

where:

- θ = angle of slope (Note: S is often substituted for $\sin \theta$) and,
- M = exponent proportional to steepness.

The exponent, M, varies with slope and is computed with the equation:

$$M = 0.6 (1 - e^{-35.835 S}) \tag{42}$$

The value of the C factor for each crop is determined from the tables in Agriculture Handbook 537 (Wischmeier and Smith 1978). In many rangeland areas, erosion pavement (rocks larger than a half in) on the surface is very effective in absorbing the kinetic energy of rainfall. We recommend including an estimate of the percentage of the soil surface covered by the erosion pavement and including it with the plant basal area to arrive at a C factor (for example, by using table 10 in Agriculture Handbook 537). Values of K and P can also be obtained for each subwatershed using Agriculture Handbook 537 or using the conservation report of SCS for each State.

Sediment Routing in Ponds

The SPUR model assumes that the sediment coming into the pond with the inflow is retained there. Thus, the outflow from the pond is assumed to be clear, and any water leaving the pond thus picks up sediment again from the channel boundaries below the pond.

APPLICATION OF THE SPUR UPLAND-HYDROLOGY MODEL

The hydrology part of the SPUR model is designed to operate with the climatic portion of the SPUR model providing the input and with the channel-routing portions for both the runoff and sediment transport. Thus, the user of the technology must be familiar with considerations in these parts of the program as well.

The conceptual configuration of a surface topography for input to the model is given in figure 3.1. In this conceptualization, there were four channel reaches (C1 . . . C4), eight lateral inputs (L1, L2 . . . L8), two upland regions (U1 and U2), and one pond (P1). The constraints shown at the bottom of the figure illustrate requirements for the computer model. These constraints allow simulation of almost any topographic or land use variation patterns into a fairly rigorous reproduction of the prototype.

Illustrations of the model application to a small watershed on Walnut Gulch follow. Walnut Gulch is an ephemeral tributary of the San Pedro River in southeastern Arizona. The watershed is an intermountain alluvial basin typical of mixed grass-brush areas encountered in Major Land Resource Area 41, the Southwestern Arizona Basin and Range. Figure 3.2 illustrates the features of stock pond watershed 23 (known locally as the Lucky Hills Watershed) on Walnut Gulch. The watershed was conceptualized for the model as one 9.1-acre upland area discharging to a 4,000-ft long channel (C1 and C2) having lateral contributing areas L1 (49.2 acres) and L2 (49.7 acres), or a total drainage of 108 acres into the pond (P1).

Tables 3.1, 3.2, and 3.3 contain the input data used in the upland hydrology part of the SPUR model for the 108-acre watershed used in the test application for the hydrology component only. The 100-day return-flow travel time was used to ensure that there was no baseflow. Similarly, the use of zero for the crack-flow factor means that the model in the test application did not consider this type of flow situation (table 3.1).

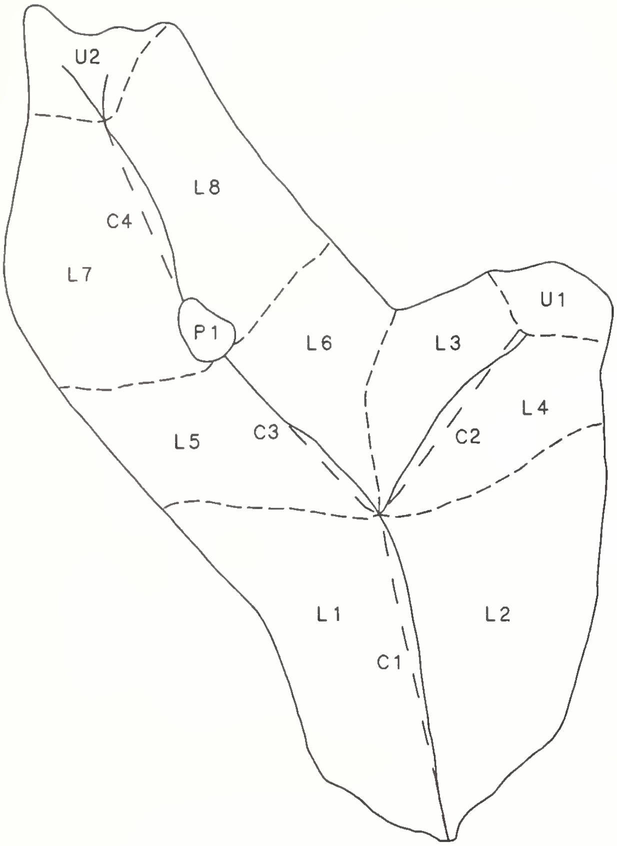


Figure 3.1
Concept of a watershed into upland areas (U1-U2), lateral areas (L1-L8), stream channel reaches (C1-C4), and ponds (P1). Model constraints are (1) each channel must have an input, either an upland region or up to two channels; (2) each channel must have one or more lateral inputs; and (3) each channel may output through a pond.

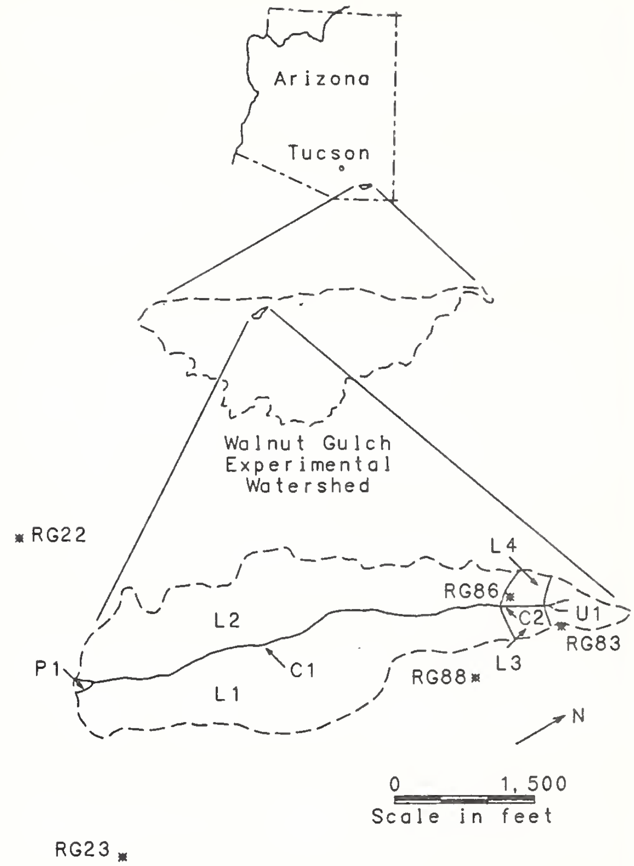


Figure 3.2
Lucky Hills Watershed used in the model evaluation showing two lateral areas (L1-L2), one upland area (U1), and a single channel reach (C1) draining into one pond (P1).

The soils data in Table 3.2 are for a Rillito-Laveen gravelly loam soil. Gelderman (1970) described this association as occurring on moderately sloping ridges formed by the deep dissection of old alluvial fans and valley plains.

These soils generally consist of deep, well-drained, medium and moderately coarse-textured gravelly soils. Because the same soil occurred in each of the three field elements simulated in the model, only one data set is included in table 3.2. The seventh layer of the model was assumed to have zero saturated hydraulic conductivity to simulate the caliche layer which persists through the area. This layer is synonymous with the limit of the most active root layers. In our experience, using greater soil depth results in the creation of an artificially large soil moisture reservoir, and, in turn, a low curve number which, therefore, simulates lower runoff than the prototype records indicate.

A sample of the output from the hydrology part of the SPUR model is given in table 3.4 for 1973. The 10.33 inches of precipitation is very near the average annual for the period of record but below the normal for the long-term record at the Tombstone, AZ gage, about 3 miles from the watershed. Monthly values of infiltration, evaporation, and plant transpiration are very representative of those for normal conditions in this environment. The table summarizes what the model predicts will happen from the fields (upland and lateral areas), from the soil profile, in the channels, and, finally, the net yield of sediment from the fields, as well as the fine material (silt and clay) and coarse material (bed load) from the channels. The output from the channel routing is documented in chapter 5.

A 17-year simulation with the SPUR hydrology component was compared with actual data from the Lucky Hills watershed for 1965-81. Figures 3.3 and 3.4 illustrate the agreement between the predicted and observed runoff for the upland area and that of the entire area. The relatively poor agreement between the observed and predicted data, as evidenced by the regression statistics in

figure 3.3, results largely from the 1975 data, where the 2.10-in simulation seriously underestimates the 2.96 in of observed runoff. Without this one year, the slope of the regression line is much closer to unity.

In figure 3.5, the cumulative observed and predicted annual runoff are compared for two curve numbers. Again, the problem of the 1975 data shows with the large departure from the one-to-one line. With the curve number equal to 87, the cumulative runoff at the end of the 17 years overpredicted the observed results. The sensitivity of the curve number model is illustrated with this figure.

Figure 3.6 illustrates the annual variability of precipitation, evapotranspiration, and transmission losses from the upland area and the entire 108-acre Lucky Hills watershed. As expected, the ET follows the precipitation fairly closely, with some noticeable exceptions like that in 1966. In 1966, the computed ET actually exceeds the precipitation because of some soil moisture carry-over from the fall of 1965. In addition, the underestimation of the runoff meant there was additional soil moisture for evaporation and transpiration in 1966. Transmission losses are notably larger on the larger and more variable watershed, as expected.

To test agreement of simulated and actual sediment yield with the MUSLE relationship in SPUR, data from the upland area (9.1 acres) (figs. 3.2 and 3.7) for 1965 through 1981 was used. The correlation coefficient of 0.90, and an intercept near zero with a slope of 1.1, indicates a close relationship between field-measured and simulated values.

CONCLUSIONS

A model has been developed which facilitates describing the spatial variability of soils, vegetation, and topography. By allowing such spatial physiographic variability, differences in hydrologic process magnitudes can be accommodated, including those which are restricted to the upland areas as contrasted with those that happen in stream channels. The fundamental precepts behind the development are felt to be in sufficient detail to facilitate describing the heterogeneity encountered in most rangeland conditions.

Table 3.1.
Parameter values input for the upland areas of the Lucky Hills Watershed

Parameter	Unit	Field		
		1	2	3
Field type		Upland	Lateral	Lateral
Soil layers	Number	8	8	8
Field area	Acres	9.1	49.2	49.7
Curve number		86	86	86
Return-flow time	Days	100	100	100
MUSLE parameters				
K		.10	.10	.10
C		.10	.13	.13
P		1.00	1.00	1.00
LS		1.30	1.30	1.30
Soil evaporation	In/day$^{1/2}$	.122	.122	.122
Crack-flow factor		0	0	0

Table 3.2
Soil data for the upland areas of the Luck Hills Watershed

Soil data	Soil-layer parameters							
	Layer 1	Layer 2	Layer 3	Layer 4	Layer 5	Layer 6	Layer 7	Layer 8
Soil porosity (in/in)	0.430	0.430	0.430	0.430	0.460	0.470	0.470	0.450
Water at 1/3 bar (in/in)	.200	.200	.200	.200	.200	.200	.200	.200
Water at 15 bar (in/in)	.037	.043	.049	.049	.059	.065	.065	.055
Saturated-soil conductivity (in/h)	.500	.500	.500	.500	.500	.500	.000	.300
Soil depth, accumulative (in)	3.000	6.500	10.000	15.000	20.000	22.500	25.000	27.000
Field capacity (in)	.535	.607	.590	.843	.799	.386	.386	.327
Maximum storage (in)	1.225	1.412	1.395	1.993	2.099	1.061	1.061	0.827

Note: Soil data for Rillito-Laveen gravelly loam soil.

Table 3.3
Climate generator input parameters and generated mean monthly max-min temperatures (°F) and solar radiation (ly) by month, Walnut Gulch, AZ

Maximum temperature
TXMD = 80.000
ATX = 17.500
CVTX = 0.085
ACVTX = -0.040
TXMW = 70.000

Minimum temperature
TN = 48.900
ATW = 17.000
CVTN = 0.110
ACVTN = -0.050

Solar radiation
RMD = 525.000
AR = 207.000
RMW = 380.000

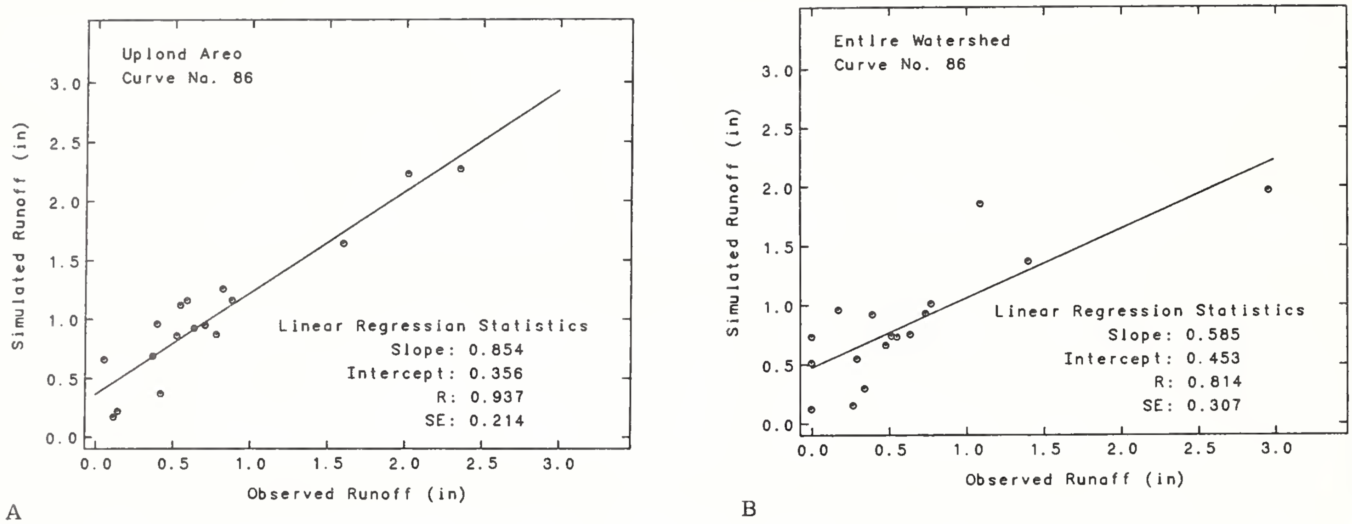
Temperature and solar radiation	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Minimum temperature (°F)	32.14	33.46	39.55	47.96	56.68	63.17	65.35	63.17	56.83	49.84	41.18	34.51
Maximum temperature (°F)	61.91	62.59	69.12	78.47	87.71	93.77	92.97	91.61	85.99	80.60	71.48	64.07
Solar radiation (ly)	330.26	399.08	484.64	610.20	686.98	721.90	647.37	597.32	510.20	435.89	342.82	298.82

Table 3.4
Sample output from the simulation with the SPUR hydrology model on the 9.1-acre Lucky Hills watershed using measured daily precipitation, by month, 1973

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
							FIELDS						
RAINFALL	0.360	1.150	2.490	0.000	0.370	0.790	3.670	0.890	0.400	0.000	0.210	0.000	10.330
INFILTRATION	0.360	1.008	2.367	0.000	0.370	0.788	2.958	0.877	0.400	0.000	0.210	0.000	9.337
RUNOFF	0.000*	0.142	0.123	0.000	0.000	0.002	0.712	0.013	0.000	0.000	0.000	0.000	0.993
							SOIL						
RETURN FLOW	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
SOIL EVAP	0.137	0.557	1.538	0.383	0.256	0.535	1.451	0.894	0.303	0.000	0.131	0.055	6.241
PLANT EVAP	0.006	0.156	0.503	0.393	0.161	0.267	1.004	0.488	0.097	0.000	0.020	0.004	3.098
DEEP PERC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
STORAGE	0.312	0.607	0.933	0.157	0.109	0.096	0.598	0.093	0.093	0.093	0.152	0.093	
							CHANNEL						
LOSSES	0.000	0.010	0.020	0.000	0.000	0.002	0.043	0.006	0.000	0.000	0.000	0.000	0.081
RUNOFF	0.000*	0.133	0.103	0.000	0.000	0.000	0.669	0.008	0.000	0.000	0.000	0.000	0.913
PEAK	0.0	3.8	1.5	0.0	0.0	0.0	15.2	0.2	0.0	0.0	0.0	0.0	15.2
BASIN WE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
LIVE VEG	133.67	151.01	226.96	299.67	327.76	392.06	661.23	596.53	343.88	177.31	137.41	110.48	
DEAD VEG	750.44	573.10	380.99	527.78	577.57	627.48	525.72	820.69	997.54	981.41	821.61	705.62	
							SEDIMENT						
FIELD SED	0.00	0.38	0.29	0.00	0.00	0.00	2.14	0.03	0.00	0.00	0.00	0.00	2.84
SILT-CLAY	0.00	0.74	0.40	0.00	0.00	0.00	4.28	0.02	0.00	0.00	0.00	0.00	5.98
BEDLOAD	0.00	1.24	0.71	0.00	0.00	0.00	7.15	0.02	0.00	0.00	0.00	0.00	9.12

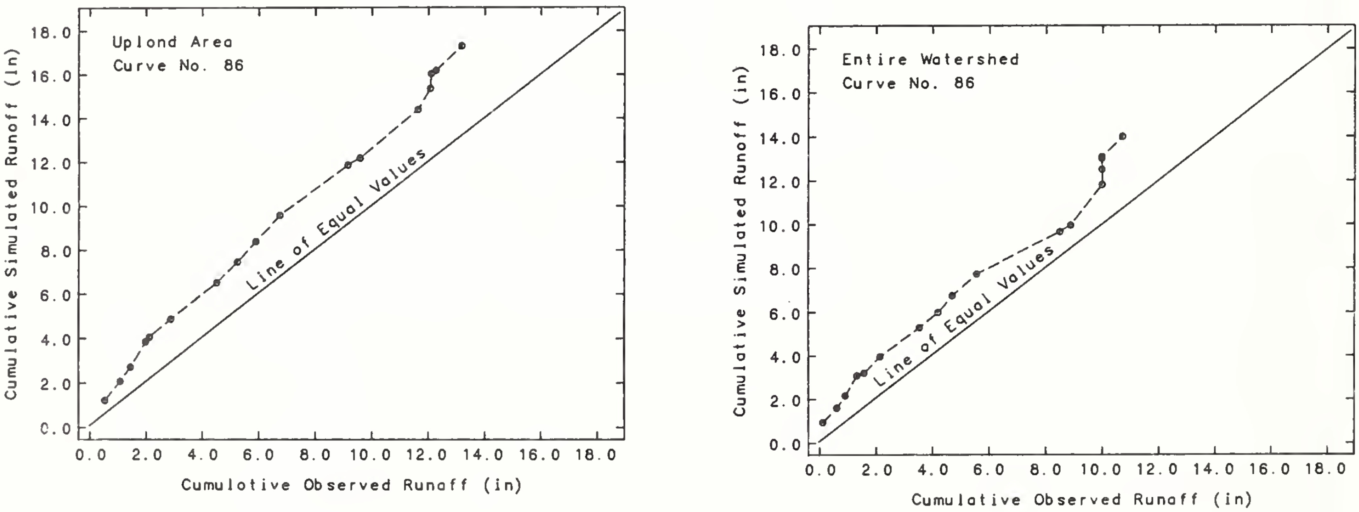
* When there is no runoff for the month in question, the computer program produces the indicated values.

NOTE: Water = inches; WE = snow water equivalent in inches; peak flow = ft^3/s; veg = 1b/ac; and sediment = tons. An acre-ft of water is 0.111 inches over the watershed.



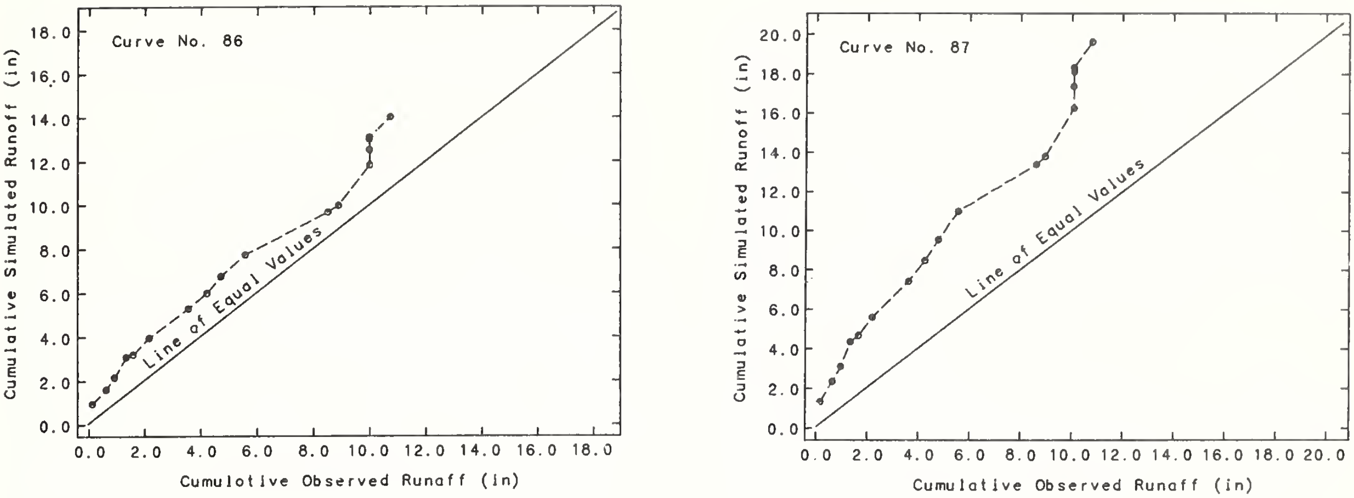
A B

Figure 3.3
Simulated versus observed annual runoff from the 9.1-acre area and the entire 108-acre Lucky Hills watershed, 1965-1981.



A B

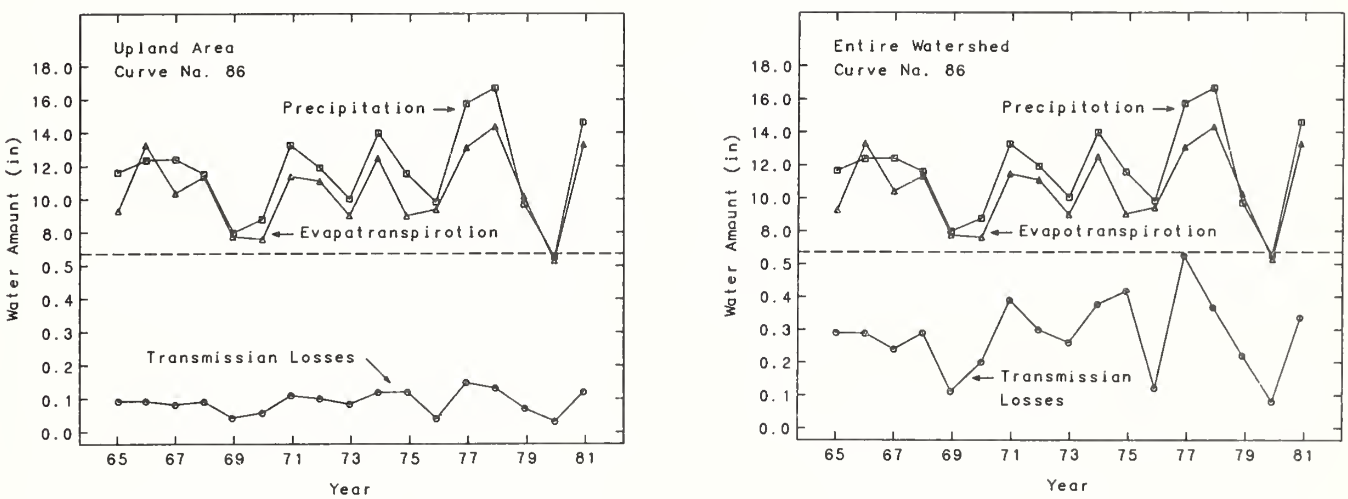
Figure 3.4
Cumulative annual predicted versus actual runoff from the 9.1-acre upland area and the entire 108-acre Lucky Hills watershed, 1965-1981.



A

B

Figure 3.5
Cumulative annual predicted versus actual runoff for the 108-acre Lucky Hills watershed for two curve numbers, 1965-1981.



A

B

Figure 3.6
Precipitation, evapotranspiration, and transmission losses for the 9.1-acre upland area and the entire watershed, 1965-1981.

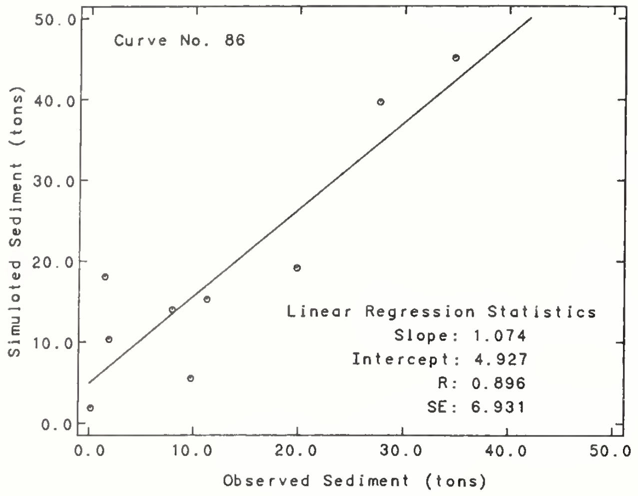


Figure 3.7
Simulated versus observed annual sediment yield using the MUSLE for the 9.1-acre upland area of the Lucky Hills watershed, 1965-1981.

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4. HYDROLOGY COMPONENT: SNOWMELT

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INTRODUCTION

The use of mathematical models designed to simulate physical processes has increased greatly within the last decade. Many of these models were developed to address specific concerns under local conditions. However, the models have later been applied at other sites, sometimes under drastically different conditions. This is especially true for several hydrologic models, most of which do not contain adequate relationships to account for snow accumulation and melt in Northern States where snowfall represents a significant part of the annual precipitation. A more general relationship is needed that will accommodate heavy, continuous snow, isolated drifts, and/or intermittent, light snow conditions, to expand the flexibility of these models.

A review of the literature indicates that three main types of snow accumulation and melt models have been developed. The first, and most common type, consists of a variety of empirical relationships generally containing one or two parameters, such as the constant-times-air-temperature concept (Riley et al. 1972, Stewart et al. 1975). The second consists of the more technically sound partial or complete energy budget approach which requires considerably more detailed data sets (Leaf and Brink 1973). The third combines both types by developing empirical relationships between readily available air temperature and each flux in the energy balance (Anderson 1973). The third type was selected for testing because (1) air temperature data are readily available, (2) the approach appeared to be technically sound, (3) the model has been tested in several climatic regions within the United States, and (4) an expected range of values for the calibration parameters was available for a variety of conditions. Initial tests on rangelands indicate that the snowmelt model provides adequate results, and it was, therefore, selected for inclusion in the SPUR model (Renard et al. 1983).

DESCRIPTION OF THE MODEL

The snowmelt model selected was developed by Eric Anderson (1973) of the National Weather Service (NWS) and is called HYDRO-17. After considerable experience and effort in developing complete energy balance models of snow surfaces, Anderson determined that for most uses, a user-oriented model would require drastic simplification and reduction in data needs. This model, HYDRO-17, meets those criteria.

It is a conceptual model of the physical processes affecting snow accumulation and snowmelt which Anderson considers mathematically signif- icant. Air temperature is used to index energy exchange across the snow-air interface. This is not the same as the degree-day method, which uses air temperature as an index to snowpack outflow. The degree-day method does not explicitly account for freezing of the melt water due to a heat deficit and the retention and transmission of liquid water, both of which cause snowpack outflow to differ from snowmelt.

Accumulation Process

The accumulation of snow in the model is simply based on the air temperature and the temperature selected to differentiate rain from snow (PXTEMP). Precipitation is considered to be snow if the air temperature is less than or equal to PXTEMP, and rain if the air temperature is greater than PXTEMP. The amount of new snow is added to the existing snowpack to establish a new total snowpack.

Melt Processes

The snowmelt processes are divided into two categories: snowmelt during rain-on-snow and snowmelt during nonrain periods. Snowmelt during rain-on-snow periods is separated from melt during nonrain periods because (1) of the difference in magnitude of the various energy transfer processes, (2) the dominant energy transfer processes during rain-on-snow periods are known, and (3) the seasonal variation in melt rates is generally different for the two processes.

Rain-On-Snow

During rain-on-snow, melt is assumed to occur at the snow surface. Following the development of the model relationships presented by Anderson (1976), the energy balance of a snow cover can be expressed as:

$$\Delta Q = Q_n + Q_m + Q_e + Q_h + Q_g \qquad (1)$$

where:

- ΔQ = change in the heat storage of the snow cover,
- Q_n = net radiation transfer,
- Q_m = heat transfer by mass changes (advected heat),
- Q_e = latent heat transfer,
- Q_h = sensible heat transfer, and
- Q_g = heat transfer across the snow-soil interface.

The units of each term in equation 1 are energy per unit area.

Upon expansion of each term in equation 1, and elimination of variables made possible by the assumptions listed below, the amount of snowmelt M (mm) during a time period Δt (h) can be determined as follows:

$$M = \Delta t[0.612 \times 10^{-9}(T_a + 273)^4 - 3.39] + 0.0125\, P_x T_a + 8.5\, UADJ[(0.9 e_{sat} - 6.11) + 0.00057\, P_a T_a] \quad (2)$$

where:

T_a = temperature of the air (°C),
P_x = water equivalent of precipitation (mm),
P_a = atmospheric pressure (mb),
e_{sat} = saturation vapor pressure at the air temperature (mb), and
UADJ = average wind function during rain-on-snow periods ($mm \cdot mb^{-1}\ \Delta t\ h^{-1}$).

The assumptions pertaining to conditions during rain-on-snow events are as follows:

1. The turbulent transfer coefficients for heat and water vapor are equal.

2. The temperature of the snow cover outflow is 0 °C.

3. The heat content of the transferred vapor is negligible; only heat transferred by precipitation is considered.

4. The isothermal snow cover is melting and the snow surface temperature is 0 °C.

5. Heat transfer across the snow-soil interface is negligible compared with energy exchange at the snow surface.

6. The change in heat storage of the snow surface becomes equal to the amount of melt.

7. Incoming solar radiation is negligible because overcast conditions prevail.

8. Incoming longwave radiation is equal to blackbody radiation at the temperature of the bottom of the cloud cover, which should be close to the air temperature.

9. The relative humidity is quite high (90 percent is used).

Under the conditions described by these assumptions, the wet-bulb temperature is essentially the same as the air temperature. The saturation vapor pressure can be computed as a function of air temperature by the relationship:

$$e_{sat} = 2.749 \times 10^8\, e^{\frac{-4278.6}{T_a + 242.8}} \quad (3)$$

The atmospheric pressure, P_a, is computed for the elevation of the site or area using a "standard atmosphere" altitude-pressure relationship which can be approximated by the expression:

$$P_a = 1012.4 - 11.34\, E_l + 0.00745\, E_l^{2.4} \quad (4)$$

where E_l = elevation (hundreds of meters).

The wind-function parameter, UADJ, is determined during the calibration process. In the model, the amount of rain must exceed 6 mm during a 24-hour period before equation 2 is used; therefore, humid overcast conditions are more likely to have occurred.

Ablation (Nonrain Periods)

Because such a wide variety of meteorological conditions can occur during nonrain periods, the energy balance equations are not used as a basis for estimating snowmelt from air temperature. Rather, an empirical air-temperature-based relationship is used in which snowmelt is determined by:

$$M = M_f\,(T_a - MBASE) \quad (5)$$

where:

M_f = melt factor,
MBASE = base temperature below which no melt is produced, and
T_a = air temperature.

The melt factor exhibits a seasonal variation due partly to the variation in incoming solar radiation, and partly to a decrease in the albedo of the snow cover with time since the last snowstorm. Seasonal variations in other meteorological factors, like vapor pressure, wind, and cloud cover, also influence the melt factor. A sinusoidal relationship between melt factor and season was developed within the model to account for this variation. This relationship is adequate for use throughout the 48 contiguous States.

Groundmelt

In some watersheds, a small amount of melt takes place continuously at the bottom of the snowpack. The melt is small on a daily basis, but it can amount to a significant quantity of water when accumulated over an entire snow season. Groundmelt adds to soil moisture storage and helps sustain baseflow throughout the winter. It is added to the snow cover outflow and to rain which falls on bare ground to obtain total rain plus melt.

Figure 4.1 shows each of the physical processes included in the model. The description of the model previously described and the following description of its parameters summarize Anderson's work, and the reader is referred to the report describing the current model for more detail (Anderson 1973, 1976). Slight variations may be noted between this work and that presented by Anderson because the SPUR model adaptation is programed to use a 24-h time step, rather than the 6-h period normally used by the NWS. A daily time step was chosen for SPUR because mean daily values of air temperature and precipitation are more generally available, and the SPUR model operates on a daily time step.

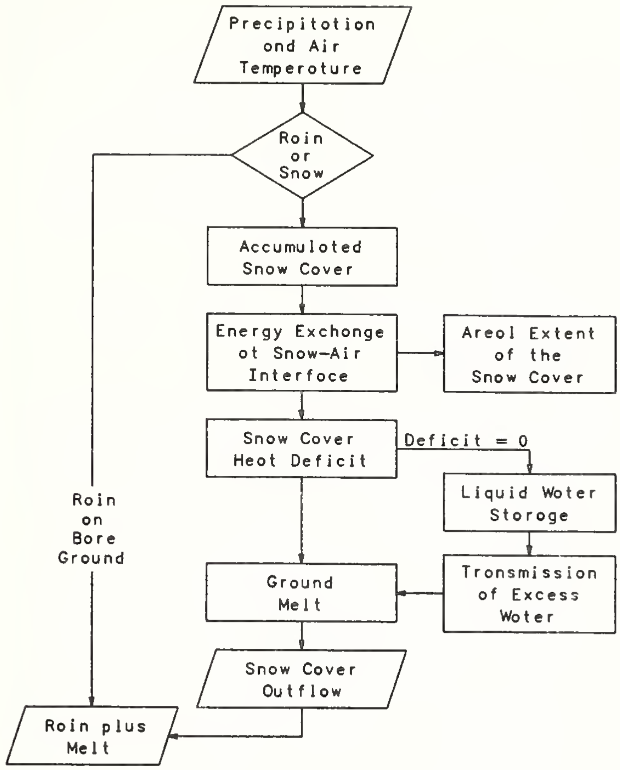

Figure 4.1
Flowchart of the snow accumulation and ablation model (HYDRO-17) from Anderson (1973).

MODEL PARAMETERS

In addition to the data requirements of temperature, precipitation, and site elevation, values must be set for six major and six minor parameters to use the model. The six major parameters are those which generally have the greatest effect on the simulation results and, therefore, require the most care in determining the proper value. These parameters with their expected range in parentheses are:

1. SCF -- (0.8 - 1.4). A snow correction factor which adjusts precipitation for gage-catch errors during periods of snowfall and implicitly accounts for net vapor transfer and interception losses. This parameter depends mainly on the wind speed at the gage site and whether the gage is shielded.

2. MFMAX -- (2.0 - 8.0) (mm/°C - 24 h). Maximum-melt factor during nonrain periods. This factor is affected by many climatic and physiographic variables such as radiation intensity, wind, forest cover, and aspect.

3. MFMIN -- (0.4 - 3.6) (mm/°C - 24 h). Minimum-melt factor during nonrain periods. The same climatic and physiographic variables that affect MFMAX also affect MFMIN in essentially the same way.

4. UADJ -- (0.0 - 0.6) (mm/mb). The average wind function during rain-on-snow periods, which is affected most by density and height of vegetation and terrain.

5. SI -- (200 - 600) (mm). The mean, areal water equivalent above which there is always 100 percent areal snow cover. This value is affected by the snowfall characteristics of the area. If the snow cover is uniform and melts at a uniform rate, the area will remain at 100 percent cover until just before the snow disappears. In contrast, especially where drifting occurs, the snow cover in some areas is so variable that bare ground appears as soon as melt begins.

6. ADPT -- Areal Depletion Curve (described more fully later). A curve which defines the areal extent of the snow cover as a function of how much of the original snow cover remains. It also implicitly accounts for the reduction in the melt rate that occurs with a decrease in the areal extent of the snow cover and is closely related to the SI parameter (fig. 4.2).

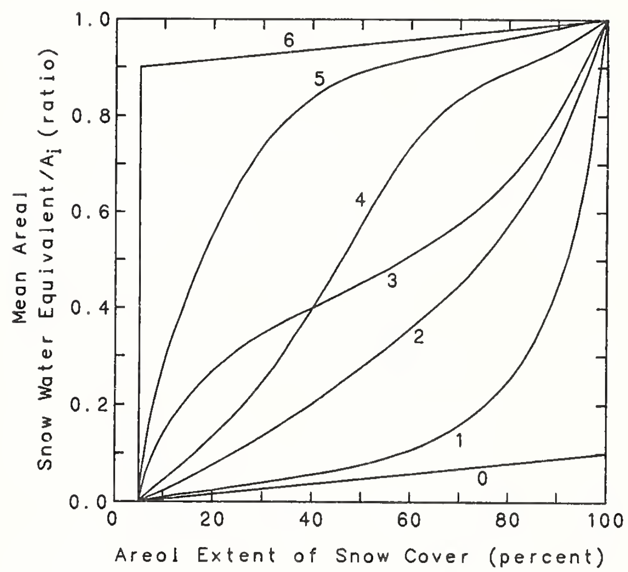

Figure 4.2
Snow cover areal-depletion curve types corresponding to ADPT values of 0, 1, 2, 3, 4, 5, and 6 (modified from Anderson 1973).

The six minor parameters can normally be determined in advance, based on a knowledge of the typical climatic and snow cover conditions for the area. These parameters and their normal range of values in parentheses are:

1. TIPM -- (0.1 - 0.5). A factor that determines how much weight is placed on the air temperature for each prior period. A small value corresponds to deep snowpacks and longer periods, while a larger value corresponds to shallow snowpacks and short periods of only a few days.

2. NMF -- (0.0 - 2.0) (mm/°C/24 h). The maximum negative melt factor. This factor is assumed to have the same seasonal variability as the surface melt factor. It is affected mostly by snow density, though climate and physiographic variables also affect heat exchange during nonmelt periods.

3. MBASE -- (0.0 - 2.0) (°C). Base temperature (normally 0 °C) for snowmelt computations during nonrain periods.

4. PXTEMP -- (0.0 - 5.0) (°C). The temperature which differentiates rain from snow (normally 0 to 2 °C).

5. PLWHC -- (0.01 - 0.05). Percent liquid-water holding capacity expressed as a decimal. Represents the maximum amount of liquid water in the snowpack which can be held against gravity drainage.

6. DAYGM -- (0.0 - 0.5) (mm). Constant rate of melt which occurs at the snow-soil interface whenever the soil is not frozen and snow is present.

The range of values presented are based on information reported by Anderson (1973) and experience in calibrating the model at several sites and climatic regimes. Although upper and lower values are presented, values outside this range can occur. Since the model has been tested over such a wide range of conditions, most of the values should be within the range presented.

MODIFICATION TO HYDRO-17

Areal Extent of Snow Cover

We have modified the input of the snow cover depletion curve by defining a new parameter, the snow cover areal depletion curve type (ADPT), which defines the specific curve for the site being modeled by a table lookup and interpolation procedure. Figure 4.2 shows the seven curves covering the feasible range of types which provide the basis for the procedure. Curves 2 through 5 correspond to curves A through D presented by Anderson (1973). Each curve is represented by 11 discrete points giving the percentage of snow cover corresponding to each one-tenth increment in the ratio of the mean, areal snow water equivalent (SWE) to the areal index (A_i). The values representing each curve are given in table 4.1.

Values of ADPT are restricted to nonnegative real numbers which are used to define snow cover areal depletion curves as follows:

1. For values of ADPT less than 6.0, the depletion curve is defined by linear interpolation between the two curves which bracket the ADPT value. The fractional part of ADPT is the interpolation factor. For example, an ADPT value of 2.5 specifies a depletion curve halfway between curves 2 and 3.

2. A value of ADPT greater than or equal to 6.0, but less than 10.0, selects curve number 6.

3. Values of ADPT 10.0 or greater are parsed into two whole numbers and a fractional part. The whole numbers define the curves between which interpolation takes place and the fractional part defines the interpolation factor. Interpolation is done between the low and high curve numbers. If the parsing of ADPT results in parsed numbers greater than 6.0, curve number 6 will be selected. For example, an ADPT of 60.4 will select a curve interpolated between curves 0 and 6 with 0.4 being the interpolation factor. A value of 24.6 will define a curve interpolated between curves 2 and 4 with 0.6 being the interpolation factor.

MODEL EVALUATION

Reynolds Creek, Idaho Snow Course Test

The HYDRO-17 model (Anderson 1973) was tested at the USDA-ARS Reynolds Creek Experimental Watershed in southwest Idaho. The Reynolds Mountain snow course at 2,073 m elevation is on the upper end of the watershed. The surrounding area is predominantly sagebrush mountain meadows with a few scattered stands of aspen, willows, and Douglas fir. Mean annual precipitation is 1,014 mm, most of which (60-70 percent) occurs as snowfall. Data used in the testing included daily maximum and minimum temperatures recorded at the Reynolds Mountain weather station and daily precipitation measured at the weather station and the snow course site. The model was evaluated using the accumulated absolute deviations of the simulated SWE from the observed SWE.

The bias of the fit also was determined, which is the algebraic sum of the deviations between simulated and measured SWE. The model was first calibrated with the 1980 water year data. The simulated snowpack for the snow course survey data was used to compute the objective and bias functions. A minimum objective function value of 144.0 mm with a bias of -26.0 SWE was obtained. Figure 4.3 depicts the fit obtained during the snow season (October 1979-June 1980) with the 1980 water year data. The correlation between the simulated and observed SWE was 0.998. Figure 4.4 shows the computer output for the calibration period, water year 1980 and test year 1970.

Table 4.1
Snow cover areal depletion curve values
(percent snow cover)

Curve type (ADPT)	Mean, areal snow water equivalent/A_i (ratio)										
	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
0	5	100	100	100	100	100	100	100	100	100	100
1	5	58	76	84	89	93	95	97	98	99	100
2	5	24	40	53	65	75	82	88	93	97	100
3	5	8	14	23	40	59	73	83	90	95	100
4	5	16	26	34	40	46	52	58	66	82	100
5	5	6	8	10	14	18	22	27	35	54	100
6	5	5	5	5	5	5	5	5	5	5	100

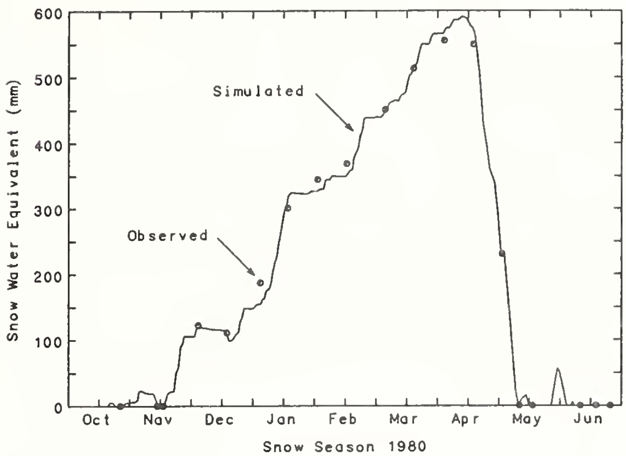

Figure 4.3
Snow water equivalent at the Reynolds Mountain snow course during the water year 1980 accumulation/ablation period. Simulated by HYDRO-17 versus observed.

A 4-year test period, including the high and low years of record, was assembled to test the validity of the calibration coefficients. The test results are shown in figure 4.5. The correlation coefficent between computed and observed SWE was 0.905, indicating that the model represents about 82 percent of the variance between the computed and observed SWE values.

The 4-year simulation shown in figure 4.5 illustrates a problem common to all temperature-driven snowmelt models. The model, which uses the ambient temperature as an index of the physical processes causing the snowpack to accumulate and melt, works very well for the snow seasons of 1971 and 1980, but causes the snowpack to melt prematurely during three test years. This finding may be verified from figure 4.4, where the poor performance of the model is caused primarily by the premature melt early in the snow season and continuing throughout the snow accumulation period. This same phenomenon also prevails during the 1972 and 1977 test years, which indicates that under certain conditions the ambient temperature fails as an index of the physical processes that cause the snow to accumulate and melt; the inclusion of additional variables such as solar radiation, wind run, and vapor pressure will be needed to improve the model. Since these data are not usually available at the sites to be simulated, the temperature data must suffice, which must be recognized as limiting the model.

A summary of the results of testing the HYDRO-17 snow model is given in table 4.2.

Lower Willow Creek, Montana Snow Course Test

A second less detailed test of the HYDRO-17 snow model was conducted at snow course sites in Montana, which more nearly represent typical field conditions. At the Reynolds Creek site, air temperature and precipitation are routinely monitored, whereas, in practice they may only be available from NWS stations often located many miles from the snow pillow sites, as is true with the Montana sites. The snow pillows are located in the Lower Willow Creek basin near Hall, MT. This basin encompasses an area of 190 sq km, with elevations ranging from about 1,433 m AMSL at the dam, to over 2,408 m at the highest point.

Average annual precipitation varies from approximately 356 mm at the lower elevation to over 762 mm at the higher elevations. Two SNOTEL recording snow pillow sites are located on the watershed. The Combination site represents a midelevation of 1,707 m and the Black Pine site, at an elevation of 2,164 m represents the upper part of the area.

Although precipitation records are now being kept for both SNOTEL sites, long-term precipitation and temperature records are available only from NWS or Forest Service stations within the general area of Lower Willow Creek. Temperature and precipitation records from three stations 11 to 29 km from the watershed boundary were evaluated. The record from Drummond, MT, which is about 16 km to the northeast of the watershed at an elevation of 1,202 m produced the best results.

REYNOLDS MOUNTAIN SNOW COURSE WY 1980 SWE SIMULATED BY DAILY HYDRO-17

MODEL PARAMETERS ARE AS FOLLOWS:

PAR NAME	VALUE	PAR NAME	VALUE
1 SCF	1.0000	7 NMF	0.3000
2 MFMAX	4.8000	8 TIPM	0.1200
3 MFMIN	2.0000	9 MBASE	0.0000
4 UADJ	0.3400	10 PXTEMP	0.0000
5 SI	0.0000	11 PLWHC	0.0100
6 ADPT	3.0000	12 DAYGM	0.3000

SNOW COVER DEPLETION CURVE PERCENT COVER VALUES

WE/AI	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
ADC	5.0	8.0	14.0	23.0	40.0	59.0	73.0	83.0	90.0	95.0	100.0

SEQ	DAY	MO-DA-YR	TMAX	TMIN	TAVE	P	MELT	RPSM	COVER	TWE	SWEOBS	DIFF
1	274	10- 1-79	21.83	10.16	15.99	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	288	10-15-79	22.38	2.38	12.38	7.32	0.00	7.32	0.00	0.00	0.00	0.00
24	297	10-24-79	14.05	-4.29	4.88	61.98	5.84	61.98	0.00	0.00	0.00	0.00
64	337	12- 3-79	11.83	-15.95	-2.06	160.93	32.20	42.77	100.00	118.17	121.92	-3.75
78	351	12-17-79	6.27	-14.84	-4.29	1.27	11.62	12.13	100.00	107.31	111.76	-4.45
94	2	1- 2-80	6.83	-15.40	-4.29	62.53	14.96	15.22	100.00	154.62	187.96	-33.34
108	16	1-16-80	0.71	-17.06	-8.17	170.56	4.22	4.22	100.00	320.97	299.72	21.25
122	30	1-30-80	0.16	-23.73	-11.79	9.30	4.21	4.21	100.00	326.05	345.44	-19.39
136	44	2-13-80	2.94	-10.40	-3.73	26.39	4.21	4.21	100.00	348.23	368.30	-20.07
155	63	3- 3-80	4.60	-9.29	-2.34	103.07	5.71	5.71	100.00	445.59	449.58	-3.99
169	77	3-17-80	1.27	-15.40	-7.06	71.53	4.21	4.21	100.00	512.91	513.08	-0.17
184	92	4- 1-80	-0.95	-14.29	-7.62	56.46	4.25	4.51	100.00	564.87	553.72	11.15
198	106	4-15-80	10.16	-12.06	-0.95	28.68	18.57	18.57	100.00	574.98	548.64	26.34
212	120	4-29-80	15.16	-4.29	5.44	12.95	346.02	358.98	100.00	228.95	228.60	0.35
226	134	5-13-80	12.94	-5.95	3.49	30.12	244.96	259.08	0.00	0.00	0.00	0.00
231	139	5-18-80	12.94	-4.84	4.05	10.34	1.70	10.34	0.00	0.00	0.00	0.00
252	160	6- 8-80	20.16	-5.40	7.38	109.63	61.42	109.63	0.00	0.00	0.00	0.00
260	168	6-16-80	17.38	-1.51	7.94	8.38	0.00	8.38	0.00	0.00	0.00	0.00
273	181	6-29-80	20.71	-1.51	9.60	9.91	0.00	9.91	0.00	0.00	0.00	0.00

OBJ = 144.2351 ADJ = -26.0613

REYNOLDS MOUNTAIN SNOW COURSE WY 70 SWE SIMULATED BY DAILY HYDRO-17
USING MODEL PARAMETERS DERIVED FROM WY 1980 CALIBRATION

SEQ	DAY	MO-DA-YR	TMAX	TMIN	TAVE	P	MELT	RPSM	COVER	TWE	SWEOBS	DIFF
63	335	12- 1-69	14.60	-17.62	-1.51	86.08	54.33	86.08	0.00	0.00	55.88	-55.88
95	2	1- 2-70	7.94	-13.17	-2.62	138.73	32.31	59.85	100.00	78.89	172.72	-93.83
108	15	1-15-70	0.71	-15.95	-7.62	101.73	3.91	3.91	100.00	176.71	213.36	-36.65
120	27	1-27-70	4.05	-10.95	-3.45	268.20	27.93	50.76	100.00	394.14	487.68	-93.54
134	41	2-10-70	8.49	-10.95	-1.23	10.13	19.78	19.78	100.00	384.50	477.52	-93.02
140	47	2-16-70	6.83	-4.84	0.99	17.35	22.40	30.17	100.00	371.68	508.00	-136.32
149	56	2-25-70	5.71	-8.73	-1.51	15.42	7.98	7.98	100.00	379.12	528.32	-149.20
162	69	3-10-70	7.38	-9.84	-1.23	45.90	31.28	31.28	100.00	393.74	609.60	-215.86
176	83	3-24-70	7.94	-8.17	-0.12	30.71	30.04	49.85	100.00	374.60	594.36	-219.76
190	97	4- 7-70	8.49	-11.51	-1.51	17.91	21.84	21.84	100.00	370.67	660.40	-289.73
204	111	4-21-70	6.83	-12.62	-2.90	82.12	14.66	14.66	100.00	438.12	716.28	-278.16
218	125	5- 5-70	16.27	-11.51	2.38	17.35	165.37	165.37	100.00	290.10	635.00	-344.90
232	139	5-19-70	19.60	-7.62	5.99	38.13	309.35	328.22	0.00	0.00	391.16	-391.16
241	148	5-28-70	19.05	1.27	10.16	17.02	0.00	17.02	0.00	0.00	0.00	0.00
246	153	6- 2-70	20.71	-0.40	10.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00
252	159	6- 8-70	22.94	1.83	12.38	11.02	0.00	11.02	0.00	0.00	0.00	0.00
259	166	6-15-70	10.16	-0.40	4.88	18.01	0.00	18.01	0.00	0.00	0.00	0.00
266	173	6-22-70	25.16	4.05	14.60	2.54	0.00	2.54	0.00	0.00	0.00	0.00

OBJ = 2398.0308 ADJ = -2398.0308

Figure 4.4
Computer output from HYDRO-17 simulating the Reynolds Mountain snow course snow water equivalent (SWE) for the water years 1970 and 1980 snow accumulation and ablation periods.

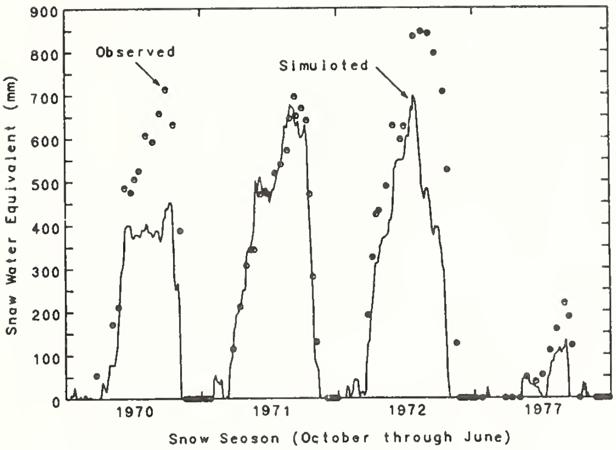

Figure 4.5
Snow water equivalent (SWE) at the Reynolds Mountain snow course during the water years 1970, 1971, 1972, and 1977 snow accumulation and ablation periods, and SWE simulated by HYDRO-17 model using the water year 1980 calibration parameters.

Table 4.2
Results of testing the National Weather Service snow accumulation and ablation model (HYDRO-17) on Reynolds Creek Experimental Watershed. Reynolds Mountain snow course site with parameter values obtained from the 1980 water year calibration

Water year	Objective function water (mm)	Bias function water (mm)	Correlation coefficient (R)	Observations (no.)
1980 (calib.)	144	-26	0.998	19
1970	398	-2,398	.914	18
1971	775	- 280	.985	25
1972	3,074	-3,074	.866	20
1977	577	- 577	.720	19
(4-yr total) 1970-1972, 1977	6,824	-6,329	.905	82

The snow correction factor (SCF) is used to adjust precipitation amounts collected under snow conditions where gage catch is normally less than actual snowfall. In these tests SCF was increased to also represent the difference in precipitation amount between the snow pillow sites and the lower elevation Drummond recording station. Since SCF is applied only when precipitation occurs as snow (that is, air temperature is less than a threshold temperature, PXTEMP, which differentiates rain from snow), the winter-season ratio of snow pillow site precipitation to Drummond Weather Station precipitation was used as the initial value for SCF. Model simulated values of the snow water equivalent are compared with snow-pillow-reported snow water equivalents in figures 4.6 and 4.7 for the five (1974-1978) snow seasons.

Only one set of parameter values was used in the 5-year simulations. Therefore, as shown in figures 4.6 and 4.7, the model overpredicts snow water equivalent for some years and underpredicts for others. Results for any one year can be improved significantly by adjusting parameters. Such adjustments indicate a change in relationships from year to year due to variations in storm tracks, inversions, and so forth, and emphasize the need for on-site temperature and precipitation data to improve results. In general, the model-produced results agree with observed data in shape and volume, although some years match better than others.

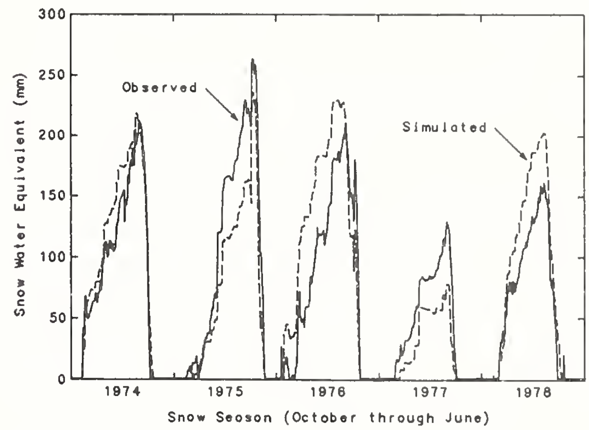

Figure 4.6
Simulated and observed snow water equivalent, Combination Snow Pillow site.

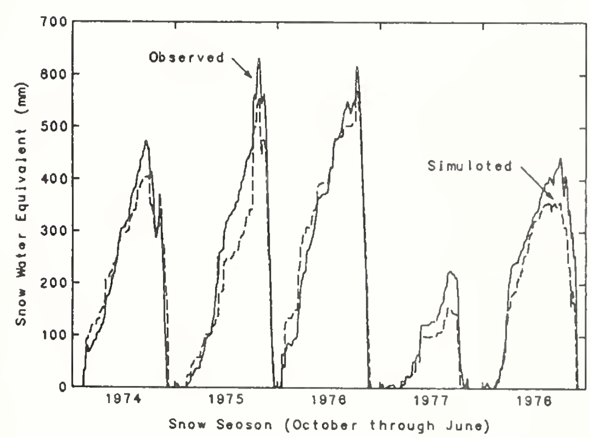

Figure 4.7
Simulated and observed snow water equivalent, Black Pine Snow Pillow site.

Calibration on Runoff Response at Upper Sheep Creek Watershed

The process of calibrating a model attempts to obtain the set of parameters that will best reproduce the observed data through minimizing a selected objective function. Next in the modeling process is the validation phase in which a totally different data set is used to compare observed and predicted values.

When calibrating or validating a snow accumulation and melt model such as HYDRO-17 and the SPUR hydrology component, the ideal situation would be to calibrate the HYDRO-17 model on observed snowpack data, such as areal coverage and water content, and use runoff data to determine parameters for the hydrology model. If parameters for both models are lumped and calibration is conducted on a single variable such as runoff, then interaction between parameters would lead to fewer physically based values, and the transfer of these values to other basins would be more difficult. Unfortunately, little rangeland watershed data are available which include the snowpack, runoff and soil moisture information required to independently check the separate components.

The closest data set that could be found was reported by Stephenson and Freeze (1974) in an intensive study of snowmelt contribution to runoff at the Upper Sheep Creek site on the east side of the Reynolds Creek Experimental Watershed in southwest Idaho. The 26 ha Upper Sheep Creek Watershed is about 850 m long by 460 wide with a southeast to northwest drainage. Elevation ranges from 1,848 to 2,036 m above-mean-sea-level and mean annual precipitation is about 406 mm. The hydrology of the Upper Sheep Creek Watershed (fig. 4.8) is dominated by deep, late-lying snowdrifts on its northeast-facing slope. During 1971, an intensive study of a section of this slope involved measurement of the snowdrift water content for the outlined zone, as well as runoff, soil moisture, and water table elevation. Since only a portion of the slope was sampled, these data were extrapolated to the entire field. The snow survey was not conducted to sample the entire drift but only the portion of interest.

The Upper Sheep Creek Watershed was divided into three fields for SPUR simulation (fig. 4.8). Soil and crop type were the same for fields 1 and 3. The snowpack data were collected for only one season and the HYDRO-17 model was calibrated on these data. Initial estimates of the parameters for the HYDRO-17 model came from the snow course parameter estimates previously reported. The point data represented by the snow course in the previous examples do not depend on the areal depletion curve as much as do the watershed data, and different estimates for SI and ADPT were required.

The hydrology parameters were calibrated over the entire period of record (October 1970 to December 1975). The parameters that varied were the condition-I curve number, the return-flow time, and the hydraulic conductivity of the soil layers.

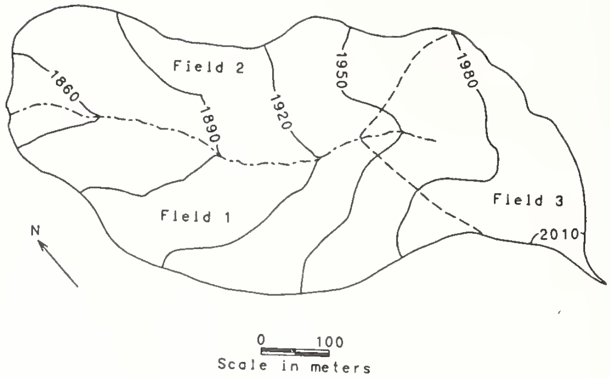

Figure 4.8
Topographic map with field site locations, Upper Sheep Creek Watershed.

The calibrated HYDRO-17 parameters are listed in table 4.3 for each field. Fields 2 and 3 were considered to be warmer because of more southerly exposures. The observed and predicted snow water contents for field 1 during 1971 are presented in table 4.4.

Table 4.3
Snow accumulation and melt model (HYDRO-17) parameters calibrated by fields

Parameter	Field 1	Field 2	Field 3
SCF	1.0	1.0	1.0
MFMAX (mm/day)	5.0	5.5	5.0
MFMIN (mm/day)	3.00	3.50	3.25
UADJ	0.20	0.20	0.20
SI (mm)	800.00	500.00	800.00
ADPT	5.0	5.0	5.0
TIPM	0.5	0.6	0.5
NMF	0.9	0.9	0.9
MBASE (°C)	0.0	0.0	0.0
PXTEMP (°C)	0.0	0.0	0.0
PLWHC	0.02	0.02	0.02
DAYGM (mm/day)	0.30	0.30	0.30

Table 4.4
Observed and predicted snow water equivalent (SWE` from field 1, Upper Sheep Creek, on specified dates in 1971

Date	Observed SWE (mm)	Predicted SWE (mm)
March 1	71	90
April 8	218	110
April 22	233	85
May 6	186	43
May 13	37	24
May 19	11	14
May 26	0	0

Apparently the predicted accumulation is about half the observed (table 4.4). The accumulated values could be increased by multiplying the precipitation by an increased SCF value. This was not done because (1) the dual-gage network used at Reynolds Creek is designed to obtain an accurate value of snowfall and (2) the sampling procedure for the water-content data was not designed to sample the entire drift, hence the snow water equivalent values are biased. The values for SI and ADPT reflect the shallow transient snowpacks that generally exist at these elevations. A type-5 areal depletion curve (ADC) initially has a rapid decrease in area with a small decrease in water content (fig. 4.2). The high values for SI allow the maximum, accumulated water content to control the ADC.

Aerial photographs of the site on April 22, 1971, and May 11, 1971 allow a qualitative check on the areal coverage calculations by the model. The photograph on April 22 indicates that the snowdrift covered 33 percent of field 1, but the model predicted a snowfall that day so coverage was 100 percent. Two days before April 22, the model predicted an areal coverage of 20 percent. On the May 11 photograph, the areal coverage was approximately 13 percent and the model predicted 7 percent.

After calibrating the snow model and determining the best-fit parameters, a calibration of the streamflow model was conducted for the entire period of record (1970-75). As noted by Stephenson and Freeze (1974), overland flow is rarely observed on the Upper Sheep Creek Watershed. This is reflected in the low value of the condition I curve number, $CN_I = 55$, which was assigned to each field. Basically, the return flow function was adjusted for each field until the best fit was achieved. From figure 4.9, it can be seen that the timing of the runoff is reasonable, but the magnitudes are variable. The coefficient of efficiency (Nash and Sutcliffe 1970) for this calibration was 0.35.

A more complete and thorough calibration and validation of the HYDRO-17 routines will require watershed data collected for these purposes. From figure 4.9, apparently the model is melting the snow at the right time intervals. Obviously, the peaks are not reproduced all that well, but this will require further work with both the snowmelt and hydrology components. Without similar data available for other watersheds, calibrating and comparing the parameters are not possible.

DISCUSSION AND CONCLUSIONS

The HYDRO-17 model (Anderson 1973) was chosen to test and for possible use in the ARS range model for Simulation of Production and Utilization of Rangelands (SPUR) because of its minimal data requirements, relatively small program size, theoretical basis, availability of parameter guidelines, and previous use in many areas.

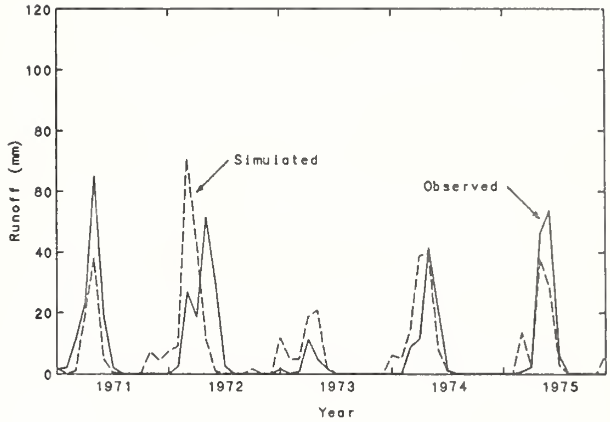

Figure 4.9
Simulated and observed monthly runoff, Upper Sheep Creek, 1971-75.

The model was tested at a snow course site and on a subwatershed of the Reynolds Creek Experimental Watershed near Boise, ID, and on two snow course sites on the Lower Willow Creek Watershed near Hall, MT. In both situations, adequate results were obtained with a minimum of calibration and parameter adjustment. The range of parameter values reported by Anderson (1973) proved adequate for both the point and basin tests at these locations.

Use of this model should provide better results over a wider range of snow accumulation and melt conditions than those provided by the simple relation used in the CREAMS model (Knisel 1980). As stated by Anderson (1973), however, situations will still exist where model results will not match actual snow conditions. In these situations only a complete energy balance method would provide good results at the expense of considerably more data than are normally available, in addition to greater program complexity.

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5. HYDROLOGY COMPONENT: WATER ROUTING AND SEDIMENTATION

L.J. Lane

INTRODUCTION

Recent developments have led to the formulation of simulation models for cultivated agricultural systems on upland areas (Stewart et al. 1975, Knisel 1980) and for models that incorporate water balance and forage-yield relations for upland areas on rangelands (Wight and Hanks 1981). However, extension of these concepts for general application on rangelands requires the development of pasture-scale and basin-scale models for rangelands incorporating special features to accurately reflect hydrologic and erosion and sediment yield processes as they occur on larger, uncultivated drainage areas. Special features of rangeland hydrology are discussed by Renard (1970) and Branson et al. (1981).

Inasmuch as hydrologic processes are complex and highly variable in time and space, it is impossible to monitor or gage hydrologic processes on each watershed where information is needed. Therefore, simulation models are needed to mimic or represent the processes of runoff and sediment yield on rangeland watersheds representing a wide variety of climatic, soil, topographic, and land use situations. As the area of interest extends from the upland areas to larger downstream areas, the relative importance of processes occurring in stream channels increases. Features of the channel network, or system, can influence the rates and amounts of runoff, as well as sediment yield.

As streamflow occurs in the channel system, it varies in the downstream direction as a result of channel features controlling flow hydraulics; as a result of the delivery of water and sediment to the channel system; and as a result of processes such as infiltration in the channel beds and banks (transmission losses) and sediment being eroded, transported, and deposited within the channel system. The purpose of this chapter is to describe the development and application of a model to simulate hydrologic, hydraulic, and sedimentation processes in alluvial stream channels on rangeland watersheds.

OBJECTIVES

The objective of the hydrologic component is to simulate the rates and amounts of runoff occurring in stream channels on rangeland watersheds and to develop procedures to estimate parameters of the model from established relationships and physical features of the watershed.

The objective of the sediment component is to simulate open-channel flow hydraulics and the resulting sediment transport rates and sediment yield. This objective includes estimating parameters of the model from established relationships and physical features of the channel system.

The overall objective of the channel component is to couple the hydrologic and sediment components to predict rates and amounts of runoff and sediment yield.

ASSUMPTIONS

The model described herein is intended for application on small rangeland watersheds, up to a few tens-of-square-miles, with well-defined channel systems. Because the sediment yield calculations are based on computed transport capacity, the procedures are designed to compute sediment transport capacity in alluvial channels with noncohesive sediments. Since many of the basic relationships incorporated in the model were developed using data from semiarid rangelands in the Western United States, the emphasis, therefore, is on streamflow occurring in ephemeral stream channels as a result of rainfall events.

DESCRIPTION

Operation of the channel component is summarized in figure 5.1. The hydrologic-simulation program estimates (based on such estimates as climatic inputs, watershed characteristics, and land use) the delivery of runoff and sediment to the channel system from the upland and lateral flow areas. The streamflow routing procedure computes (based on the upland and lateral inputs and features of the channel system) estimates of runoff volume, peak rate of runoff, and flow duration at any position in the channel system. Based on features of the stream channel and an approximate shape for the runoff hydrograph, the hydraulic component computes velocity, depth of flow, hydraulic radius, and shear stress for nine discrete intervals over the duration of flow in the channel. Using features of the channel and the hydraulic variables, the sediment component computes transport capacity for sediment particles in up to 10 discrete size classes, including suspended and bed load. Finally, sediment transport rates are integrated over the nine intervals used to approximate the hydrograph to estimate sediment yield at any point in the channel system.

Unique features of the model include the ability of the streamflow routing procedure to incorporate reductions in runoff volume and peak rate as a result of transmission losses and the ability of the hydraulic component to approximate spatially variable and unsteady flow through the hydrograph approximation technique. The purpose of the hydrograph approximation is to include some aspects of runoff variations in space and time without using the complete dynamic equations for spatially varied, unsteady flow. The hydrograph approximation technique enables use of total storm rainfall, rather than time-intensity data, and the

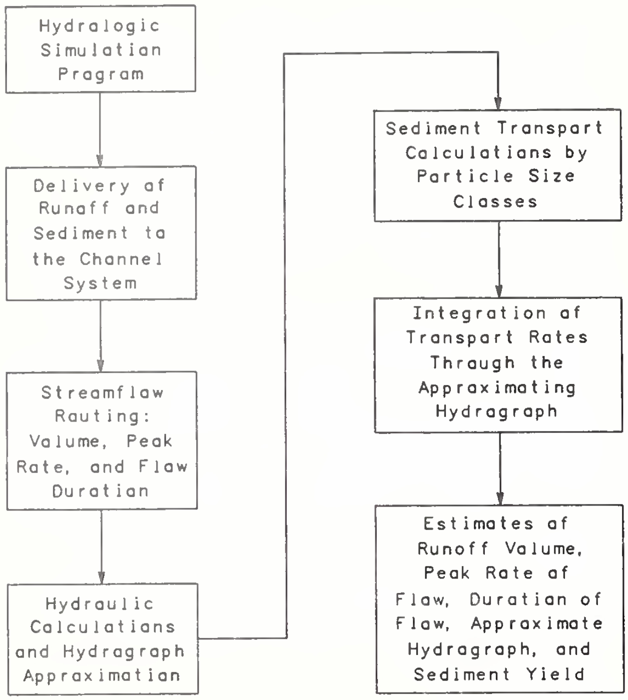


Figure 5.1
Logic diagram for computation of runoff and sediment yield from rangeland watersheds.

resulting computations for runoff volume, peak rate, and flow duration are much simpler than dynamic flood routing.

By changing runoff volume, peak rate, and duration, and thus the approximating hydrograph in the downstream direction, spatial variability due to changes in channel geometry, transmission losses, and lateral inflow is approximated. By changing the flow rate, depth, velocity, and shear stress for each time interval on the approximating hydrograph, unsteady flow at a channel cross section is approximated. The assumption of uniform and steady, or normal flow during each of nine intervals on the approximating hydrograph allows application of the Manning equation to compute flow variables and application of sediment transport equations based on the normal-flow assumption.

Background material by process or component is summarized in table 5.1. The references in table 5.1 provide the scientific basis for the channel component described herein.

STREAMFLOW ROUTING

Although the procedures described herein were derived for ephemeral stream channels with transmission losses, they can be applied, resulting in somewhat coarser approximations, in alluvial channels without significant transmission losses.

Transmission Losses

Many semiarid watersheds have broad, alluvium-filled channels which abstract large quantities of streamflow (Babcock and Cushing 1941; Burkham 1970a, 1970b; Renard 1970). These abstractions, which are called transmission losses, are important because water is lost as the flood wave travels downstream, and thus, runoff volumes are reduced. They are an important part of the water balance because they support riparian vegetation and recharge local aquifers and regional ground water (Renard 1970). Procedures are needed to estimate runoff and transmission losses in ephemeral streams.

Several procedures have been developed to estimate transmission losses. These procedures range from inflow-loss-rate equations (Burkham 1970a, 1970b; SCS 1972), to simple regression equations (Lane et al. 1971), to simplified differential equations for loss rate (Jordan 1977; Lane 1983), to storage routing as a cascade of leaky reservoirs (Wu 1972; Peebles 1975), and to kinematic wave models incorporating infiltration (Smith 1972).

Therefore, procedures range in complexity for estimating runoff in ephemeral streams with transmission losses. As a rule, the simplified procedures require less information about physical features of the watersheds but are less general in their application. The more complex procedures may be more physically based, but they require correspondingly more data and more-complex computations.

The simulation model presented herein was developed as a procedure for practical applications. The model represents a compromise between the more physically based, deterministic models and the more simplified procedures described earlier. The resulting model is constructed to require a minimum of observed data for calibration and to provide a means of making predictions on ungaged watersheds.

Generally, runoff from semiarid watersheds follows periods of thunderstorm rainfall; at other times, the stream channels are normally dry. Runoff is accompanied by substantial infiltration losses in the stream channels. These losses, and the usually steep slopes of the channels, tend to produce sharply peaked runoff hydrographs. The resulting shape of the hydrographs, which starts from and ends in a condition of no flow, consists of a fairly narrow triangular peak followed by a relatively longer recession of low flow. The time to peak (time from beginning of runoff to the hydrograph peak) is usually shorter than the recession time. This characteristic shape of the runoff hydrographs indicates that they can be fairly well approximated if the runoff volume, peak rate, time to peak, and duration of flow are known. Moreover, if the ratio of time to peak and flow duration is relatively constant, then the relation between runoff volume and peak rate is nearly linear. Based on these observations, the model described herein simulates a runoff volume and flow duration and peak rate of flow as a function of runoff volume and flow duration.

To route flow through the channel network, peak discharge as well as runoff volume from the upland and lateral flow areas must be known. Peak discharge is assumed to be a function of runoff volume and time characteristics of the runoff hydrograph. Peak discharge of a unit hydrograph from small areas can be estimated from runoff volume and time to peak (SCS 1972) as:

$$Q = \frac{484\ V\ A}{T_p} \tag{1}$$

where, in English units, the variables are:

- Q = peak rate, ft^3/s,
- V = runoff volume, in,
- A = drainage area, mi^2, and
- T_p = time to peak, h.

The factor 484 converts the flow derived from a triangular unit hydrograph from square miles-inches per hour to cubic feet per second. If time to peak, T_p, is assumed to be a constant proportion of flow duration, D, and discharge is expressed in inches per hour, then equation 1 becomes:

$$Q = \frac{484\ c\ V}{640\ D} \tag{2}$$

where:

- Q = peak discharge, in/h,
- D = flow duration, h,
- T_p = D/c, and
- c = the ratio of flow duration to time to peak.

The conversion factor 640 is the number of acres per square mile. For a constant c, equation 2 is of the form:

$$Q = C_5 \frac{V}{D} \tag{3}$$

where C_5 is a dimensionless parameter expressing hydrograph shape.

The use of a double-triangle unit hydrograph as a model for unit hydrographs of small watersheds has been proposed by Ardis (1972, 1973) with results for a number of watersheds published in a report by TVA (1973). These procedures were applied to a small semiarid watershed by Diskin and Lane (1976). Based on analysis of 10 hydrographs from a 1.6 ha (4-acre) watershed, they found for a one-minute hydrograph:

$$u = 6.6 \frac{V}{\bar{D}} \tag{4}$$

where u is the peak of the unit hydrograph, V is runoff volume in inches, and $\bar{D}$ is the duration of the mean unit hydrograph in hours. By convoluting the unit hydrograph with observed rainfall excess patterns, the relation between runoff volume, mean duration of flow, and peak rate of runoff is:

$$Q = 4.82 \frac{V}{\bar{D}} \tag{5}$$

or:

$$C_5 = 4.82$$

Using data from 15 semiarid watersheds in Arizona with 10 to 35 years of record, Murphey et al. (1977) found that mean flow duration is related to drainage area as:

$$\bar{D} = C_1 A^{C_2} = 2.53 A^{0.2} \tag{6}$$

where:

- $\bar{D}$ = mean duration of flow, h,
- A = drainage area, mi^2, and
- C_1, C_2 = parameters.

The coefficient of determination for equation 6 was 0.78, with a standard error of estimate of 21 percent. They also found that mean runoff volume per runoff event was related to drainage area as:

$$\bar{V} = C_3 A^{C_4} = 0.05 A^{-0.2} \tag{7}$$

where:

- $\bar{V}$ = mean runoff volume, in,
- A = drainage area, mi^2, and
- C_3, C_4 = parameters.

The coefficient of determination for equation 7 was 0.61, with a standard error of estimate of 28 percent.

A similar equation for mean peak discharge is:

$$\bar{Q} = 0.10 A^{-0.38} \tag{8}$$

where:

- $\bar{Q}$ = mean peak discharge, in/h, and
- A = drainage area, mi^2.

Combining equations 6, 7, and 8, from Murphey et al. (1977), the equation corresponding to equation 3 is approximately:

$$Q = 5.06 \frac{\bar{V}}{\bar{D}} \tag{9}$$

or C_5 = 5.06, which is close to the value of 4.82 found by Diskin and Lane (1976) in an independent analysis.

The procedure used is to compute runoff volume from the upland and lateral flow areas using the hydrologic model for uplands. Next, mean flow duration, using equation 6, and peak discharge, using equation 3, are calculated. The runoff volumes are then taken as upland or lateral input into a channel segment for the routing

Table 5.1
Selected references forming the basis of the channel component model

Process or component	Comment	References
STREAMFLOW ROUTING:	Overview of model	Lane (1982a).
Transmission losses.	Background, routing equations, parameter estimation.	Babcock and Cushing (1941), Renard (1970), Lane et al. (1971), Smith (1972), Jordan (1977), Lane (1983).
Hydrograph shape.	Influence of basin characteristics	SCS (1972), Murphey et al. (1977).
Approximating hydrograph.	Double-triangle approximation	Ardis (1972, 1973), Diskin and Lane (1976).
	Piecewise approximation	Lane (1982b).
	Hydraulics	Chow (1959).
SEDIMENT ROUTING:	Overview of model	Lane (1982b).
Transport capacity.	Suspended load	Bagnold (1956, 1966).
	Bed load	Straub (1935), Graf (1971).
Sediment yield.	Yield by size fractions and total yield.	Lane (1982b).

calculations. As will be shown in the next section, estimates of mean runoff volume and mean flow duration are also used to compute transmission loss parameters for a channel segment.

In the absence of lateral inflow, if observed inflow-outflow data for a channel reach are related by regression analysis (Lane et al. 1971), then an equation of the form:

$$V(x,w) = \begin{cases} 0 & V_{up} \leq V_o(x,w) \\ a(x,w) + b(x,w)\, V_{up} & V_{up} > V_o(x,w) \end{cases} \qquad (10)$$

results, where:

$a(x,w)$ = regression intercept (acre-ft or m^3),
$b(x,w)$ = regression slope,
$V_o(x,w)$ = threshold volume (acre-ft or m^3),
$V(x,w)$ = outflow volume (acre-ft or m^3),
V_{up} = inflow volume (acre-ft or m^3),
x = length of channel reach (mi or km), and
w = average width of flow (ft or m).

By setting $V(x,w) = 0.0$ and solving for V_{up}, the threshold volume is:

$$V(x,w) = \frac{-a(x,w)}{b(x,w)} \qquad (11)$$

This is the volume of inflow required before outflow begins. Inflow volumes less than $V_o(x,w)$ will all be lost or infiltrated into the channel alluvium.

Based on the preceding empirical observations and the work of Jordan (1977), using an ordinary differential equation, Lane (1983) approximated the rate of change in runoff volume with distance as:

$$\frac{dV}{dx} = -w\,[c + k\,V(x,w)] \qquad (12)$$

where c and k are parameters and the other variables are as described above. The solution to equation 12 is:

$$V(x,w) = \frac{-c}{k}(1 - e^{-kxw}) + V_{up}\, e^{-kxw} \qquad (13)$$

where $V_{up} = V(x = 0,w)$ = the upstream inflow volume. By letting $x = w = 1$, Lane (1983) defined a unit channel where $a(1,1) = a, b(1,1) = b$, and $c = -k \frac{a}{1-b}$, so that equation 13 becomes:

$$V(x,w) = \frac{a}{1-b}(1 - e^{-kxw}) + V_{up}\, e^{-kxw} \qquad (14)$$

Notice that if the following equivalence is made:

$$b(x,w) = e^{-kxw} \qquad (15)$$

and:

$$a(x,w) = \frac{a}{1-b}(1 - e^{-kxw}) = \frac{a}{1-b}[1 - b(x,w)] \qquad (16)$$

then equation 14 is identical to the regression model described by equation 10. Therefore, given observed inflow-outflow data for a channel reach, least squares analysis can be used to estimate parameters in the differential equation, equation 12, or its solution, equation 14.

If lateral flow areas contribute inflow along the channel reach, and if this flow can be considered approximately uniform with distance along the channel reach, then equation 12 becomes:

$$\frac{dV}{dx} = -w\,[c + k\,V(x,w)] + \frac{V_{LAT}}{x} \qquad (17)$$

where V_{LAT} is the volume of lateral inflow. The solution to equation 17 is:

$$V(x,w) = a(x,w) + b(x,w)\,V_{up} + \frac{V_{LAT}}{kxw}[1 - b(x,w)] \qquad (18)$$

where $a(x,w)$ and $b(x,w)$ are defined by equations 15 and 16. If the quantity $(1-b(x,w))/kw$ is denoted $F(x,w)$, then equation 18 becomes:

$$V(x,w) = a(x,w) + b(x,w)\,V_{up} + F(x,w)\,\frac{V_{LAT}}{x} \qquad (19)$$

where $a(x,w)$, $b(x,w)$, and $F(x,w)$ are parameters to be determined for a particular channel reach.

The basic equation for the transmission loss model (equation 19) involves upstream input (V_{up}), lateral inflow along the channel reach (V_{LAT}), length of the stream segment (x), width of the channel (w), and the parameters $a(x,w)$, $b(x,w)$, and $F(x,w)$. Given a runoff volume from equation 19, and an estimate of the hydrograph-shape parameter and a mean flow duration, then equation 3 is used to estimate peak discharge at the end of the channel segment. The procedure is repeated for each channel segment used to represent the channel system in a watershed. Each exterior channel segment receives input from an upland area and lateral inflow along its reach from two lateral contributing areas. Each interior channel segment receives upstream inflow from one or two tributary channels and lateral inflow along its reach from two lateral contributing areas. The channel network and its contributing areas are used to represent the entire drainage basin or watershed.

Data representing 139 events from 14 channel reaches in Arizona, Texas, Kansas, and Nebraska were analyzed. Based on these data, the unit channel parameters were estimated as:

$$a = -0.00465\,K\,\bar{D} \qquad (20)$$

and:

$$k = -1.09\,\ln(1 - 0.00545\,K\,\frac{\bar{D}}{\bar{V}}) \qquad (21)$$

where:

- a = unit channel intercept (acre/ft),
- K = effective hydraulic conductivity (in/h),
- $\bar{D}$ = mean duration of flow (h),
- $\bar{V}$ = mean volume of flow (acre/ft), and
- k = decay factor $(ft/mi)^{-1}$.

Given these parameter values, the transmission loss parameters are:

$$b = e^{-k} \qquad (22)$$

$$b(x,w) = e^{-kxw} \qquad (23)$$

$$a(x,w) = \frac{a}{1-b}(1 - e^{-kxw}) = \frac{a}{1-b}[1 - b(x,w)] \qquad (24)$$

and:

$$F(x,w) = \frac{1 - b(x,w)}{kw} \qquad (25)$$

Equations 20 through 25 define the transmission loss parameters to be used in the basic transmission loss model described by equation 19.

In addition to these analyses, data were obtained from 14 other channel reaches in Arizona (Wilson et al. 1980) and from seepage rates in unlined canals (Kraatz 1977). This information was used to derive estimates of effective hydraulic conductivity from alluvial characteristics as summarized in table 5.2.

The transmission loss component (as part of a basin-scale simulation model) was tested using data representing 222 runoff events from eight experimental watersheds on the Santa Rita Experimental Range near Tucson, Arizona. The model was also applied to predict annual flood series from 13 years of data on a small watershed

Table 5.2
Effective hydraulic conductivity for transmission losses in channel alluvium[1/]

Bed material group	Characteristics of bed material	Effective hydraulic conductivity[2/] (in/h)
1--Very high loss rate	Very clean gravel and large sand median particle size d_{50} > 2 mm.	> 5.0
2--High loss rate	Clean sand and gravel under field conditions d_{50} > 2mm.	2.0 - 5.0
3--Moderately high loss rate	Sand and gravel mixture with less than a few percent silt-clay.	1.0 - 3.0
4--Moderate loss rate	Mixture of sand and gravel with significant amounts of silt-clay.	0.25 - 1.0
5--Very low loss rate	Consolidated bed material with high silt-clay content.	0.001 - 0.1

[1/]Based on analysis of data from 14 channel reaches in Arizona, Texas, Kansas, and Nebraska, data from 14 other channel reaches in Arizona, and canal seepage rates in unlined canals.

[2/]Values of effective hydraulic conductivity reflect the flashy, sediment-laden character of many ephemeral streams, and thus, do not represent clear-water infiltration rates at steady state.

near Tombstone, Arizona and for 30 years of annual flood series on a small watershed near Safford, Arizona. The results of these analyses are summarized by Lane (1982a), wherein the model produced reasonable estimates of mean runoff volumes and peak rates and accurately simulated flood frequency distributions.

Parameter Estimation

Parameter estimation techniques are summarized in table 5.3. These techniques are based on the transmission loss analyses previously summarized, the hydrograph analysis for semiarid watersheds (Murphey et al. 1977), and for subhumid watersheds (Lane et al. 1975) and established hydrologic relationships (SCS 1972).

The parameter values shown in table 5.3 should produce reasonable estimates for small rangeland watersheds where streamflow is intermittent or ephemeral. However, if hydrologic data are available, hydrograph and regression analysis can be used to estimate values of effective hydraulic conductivity, K, and the hydrograph parameters C_1 to C_5.

In the absence of observed hydrologic data, table 5.3 can be used to estimate parameters for the hydrologic portion of the channel component. However, engineering judgment should be used to make sure the parameter estimates are reasonable, so that the model will produce reasonable estimates of runoff rates and amounts. While it is impossible to anticipate all circumstances, some general rules of applicability can be stated. The model is not intended for application in perennial streams or on watersheds where the runoff is dominated by snowmelt runoff. This includes watersheds with significant base flow regime where the ground water component dominates the streamflow. As a general rule, the model probably does not apply to watersheds where the mean annual precipitation is in excess of 20 in, or where the mean annual runoff is much in excess of 1 in.

The model is intended for application on small watersheds up to a few tens-of-square-miles. For larger watersheds, it is difficult to include sufficient channel segments to accurately represent the drainage network. The model is intended to simulate runoff over a large range in storm size. For large storms, however, out-of-bank flow may occur, which would necessitate adjusting estimates of channel width and effective hydraulic conductivity for out-of-bank flow.

Example Hydrographs

The routing procedure used herein assumes a characteristic hydrograph shape where the time to peak is 20 percent of the flow duration; the time to the inflection point on the recession is 40 percent of the flow duration; and the discharge at the inflection point is 20 percent of the peak discharge. The equations describing the double-triangle approximating hydrograph are:

$$\begin{cases} t = 0 & (26) \\ q = 0 & (27) \end{cases}$$

Table 5.3
Parameters in the transmission loss and streamflow routing procedures

Parameter or variable	Range in values	Source of estimate and comments
Watershed Area A	--	Topographic map; drainage area contributing to the channel segment.
Channel Length (x) Width (w)	--	Topographic map and field observations.
Hydraulic conductivity (K)	0.001 - 5.0	Table 5.2 or runoff data; function of channel alluvium, antecedent moisture, and so forth.
Hydrograph parameters:		
C_1	2.0 - 5.5	Murphey et al. (1977) or hydrograph analysis.
C_2	.2 semiarid to .5 subhumid	Murphey et al. (1977) or hydrograph analysis.
C_3	.03 - .07 semiarid	Murphey et al. (1977) or hydrograph analysis.
C_4	-.2 semiarid to .0 subhumid	Murphey et al. (1977) or hydrograph analysis.
C_5	2.8 - 6.0	Murphey et al. (1977), SCS (1972), or hydrograph analysis.
$\bar{D}$	> 0.0	$\bar{D} = C_1 A^{C_2}$, mean duration of flow (h).
$\bar{V}$	> 0.0	$\bar{V} = C_3 A^{C_4}$, mean runoff volume (in), must convert to acre-ft.

$$t = t_p = 0.2D \qquad (28)$$

$$t = Q_p \qquad (29)$$

$$t_1 = 2t_p = 0.4D \qquad (30)$$

$$q_1 = 0.2Q_p \qquad (31)$$

$$t = D \qquad (32)$$

$$q = 0 \qquad (33)$$

where D is the equivalent duration for the standard hydrograph shape (equations 26 through 33). The mean duration for the transmission loss equation is:

$$\bar{D} = C_1 A^{C_2} \qquad (34)$$

and the estimated peak discharge is:

$$Q_p = C_5 \frac{V}{\bar{D}} \qquad (35)$$

The quantity A, in equation 34, is the drainage area, in square miles, above the channel segment; values of t are in hours; values of q are in inches per hour; and the quantity V, in equation 35, is the runoff volume, in inches, from the transmission loss equation (equation 19). Integrating straight line segments through the points described by equations 26 through 33, the volume of runoff under the standard approximating hydrograph is:

$$V = \frac{7}{25} Q_p D = 1.4\, Q_p t_p \qquad (36)$$

which means that the equivalent duration is given by:

$$D = \frac{25}{7}\frac{V}{Q_p} = \frac{25}{7}\frac{\bar{D}}{C_5} \qquad (37)$$

where $\bar{D}$ is given by equation 34 and C_5 is a parameter value as shown in table 5.3. Equation 37 means that, when C_5 is less than 25.0/7.0 = 3.57, the equivalent duration for the standard approximating shape is greater than $\bar{D}$, and when C_5 is greater than 25.0/7.0, the equivalent duration is less than $\bar{D}$. By using D, from equation 37 in the standard approximating hydrograph, the volume, V, from equation 19, and the peak discharge, Q_p, from equation 35, and V from equation 36, are preserved or matched, but the hydrograph duration, D, is more or less than $\bar{D}$, depending on the ratio of 25.0/7.0 to C_5. Since C_5 varies from 6.0 to 2.8 (table 5.3), the equivalent duration, D, is always in the range of 0.6 $\bar{D}$ to 1.3 $\bar{D}$. The reason for adopting a standard approximating hydrograph for sediment routing in the channel is to facilitate use of a single piecewise normal approximating hydrograph, as discussed later.

To summarize, the mean volume of runoff for a channel reach (V in equation 7) and the mean duration of flow ($\bar{D}$ in equation 34) are used in equation 19 to predict runoff volume, and in equation 35, to predict peak discharge. Equation 37 is then used to compute an equivalent duration of flow for the standard approximating hydrograph (equations 26 through 33). The standard approximating hydrograph is then used to approximate the runoff hydrograph at the end of the channel segment. Values of effective hydraulic conductivity are selected from table 5.2 and the parameters C_1 through C_5 are selected from table 5.3. This parameter set and the appropriate equations are used to compute runoff volume, peak discharge, and an approximate hydrograph shape.

OPEN-CHANNEL FLOW HYDRAULICS

The sediment transport calculations are based on two major hydraulic assumptions. These are the assumptions, for simplicity in the calculations, of rectangular channel cross sections and of normal flow.

Under these conditions, the average velocity of flow is given by an empirical equation, called the Manning equation, as:

$$V = \frac{1.49}{n} S^{\frac{1}{2}} R^{\frac{2}{3}} \qquad (38)$$

where:

V	= average velocity, ft/s,
S	= slope of the channel bottom,
R	= hydraulic radius, ft, and
n	= Manning's roughness coefficient, s/ft$^{1/3}$.

The hydraulic radius for a rectangular channel is:

$$R = \frac{A}{WP} = \frac{WD}{W + 2D} \qquad (39)$$

where:

A	= cross-sectional area, ft^2,
P	= wetted perimeter, ft,
W	= channel width, ft, and
D	= depth of flow, ft.

The continuity equation is of the form:

$$Q = A V = W D V \qquad (40)$$

where:

Q	= discharge rate, ft^3/s,
A = WD	= cross-sectional area, ft^2, and
V	= average velocity, ft/s.

The depth of flow, which satisfies equations 38 and 40, is called normal depth. Flow, where the depth is normal, is called normal flow.

Hydraulic Roughness

The roughness coefficient, n, in equation 38, has been tabulated for a number of channel types (Barnes 1967) and represents the resistance to flow provided by the channel bed and banks. This resistance, or roughness, is called the total roughness. Values of total roughness coefficients, n_T, for various channel types are shown in table 5.4.

Correction for Wall or Bank Roughness

Since the flow resistance contributed by the channel banks (wall roughness) is not directly involved in transporting sediment near the channel bed, it is possible to separate its influence from the influence of the bed. Following Einstein (1942, 1944, 1950), the total cross-sectional area, A_T, is divided into an area pertaining to the wall, A_w, and an area pertaining to the bed, A_b, as:

$$A_T = A_w + A_b \qquad (41)$$

Now, if the energy gradient, S, and the velocity, V, are the same for the wall and bed, and the area is defined as the product of hydraulic radius and wetted perimeter, A = RWP, then equation 41 becomes:

$$R_T (W + 2D) = R_w (2D) + R_b W \qquad (42)$$

By the Manning equation, hydraulic radius is:

$$R = \left[\frac{nV}{1.49 S^{\frac{1}{2}}}\right]^{\frac{3}{2}} \qquad (43)$$

where V is velocity and S is slope. Substituting equation 43 into equation 42, where V and S are common to all terms, produces:

Table 5.4
Approximate hydraulic roughness coefficients for open-channel flow[1/]

Total Manning's n n_T		Description of channel
(0.02 - 0.10)		Excavated or dredged channels
0.022	1.	Earth, straight, uniform, and clean.
.027	2.	Same, but with some short grass or weeds.
.025	3.	Earth, winding and sluggish, with no vegetation.
.030	4.	Same, but with some grass or weeds.
.080	5.	Channels not maintained; weeds and some brush.
(0.03 - 0.10)		Natural streams
.030	1.	Clean and straight; no rifts or deep pools.
.040	2.	Clean and winding; some pools and shoals.
.048	3.	Clean and winding; some weeds, stones, and pools.
.070	4.	Sluggish reaches with weeds and deep pools.
(0.012 - 0.040)		Wide alluvial channels
.018 - .030	1.	Ripples bed form, sediments finer than 0.6 mm, Froude Nos. < 0.37.
.020 - .040	2.	Dunes bed form, Froude Nos. 0.28 to 0.65.
.014 - .030	3.	Transitional bed form, Froude Nos. 0.55 to 0.92.
.012 - .030	4.	Antidunes bed form, Froude Nos. > 1.0.

[1/] Values are for total roughness coefficient, n_T.

Source: Data for excavated or dredged channels and natural streams from Chow (1959); for wide alluvial channels, from ASCE (1969) and Richardson (1971).

$$n_T^{\frac{3}{2}}(W + 2D) = n_W^{\frac{3}{2}}(2D) + n_b^{\frac{3}{2}} W \qquad (44)$$

with solution for the hydraulic roughness of the bed, n_b, as:

$$n_b = \left[n_T^{\frac{3}{2}} + \frac{2D}{W}\left(n_T^{\frac{3}{2}} - n_W^{\frac{3}{2}}\right)\right]^{\frac{2}{3}} \qquad (45)$$

Geometric considerations suggest that the least value of R_b is 1/2 R_T, which means, as a minimum:

$$n_b \geqq \left[\frac{1}{2}\right]^{\frac{2}{3}} n_T \qquad (46)$$

and at a maximum:

$$n_W \leqq \left[\frac{W + 4D}{4D}\right]^{\frac{2}{3}} n_T \qquad (47)$$

Equation 45 is evaluated for n_b, subject to equation 46, as a constraint (that is, n_b is greater than $(1/2)^{2/3}$ n_T), which means that the hydraulic radius of the bed is:

$$R = \left[\frac{n_b V}{1.49 S^{\frac{1}{2}}}\right]^{\frac{3}{2}} \qquad (48)$$

Table 5.5 can be used to estimate n_T and n_W subject to the constraints on n_W as:

$$n_T \leqq n_W \leqq \left[\frac{W + 4D}{4D}\right]^{\frac{2}{3}} n_T \qquad (49)$$

The procedure is to select a value of n_T from table 5.4, or the second column in table 5.5, and to select a value of $n_W > n_T$ from the third column of table 5.5. The computer program is written so that n_W must satisfy the constraint given by equation 47.

Correction for Grain Resistance

The grain, or particle resistance coefficient, n_g, is related to a representative grain size to the 1/6 power (Strickler 1923). This can be approximated as:

$$n_g = 0.0132\,[d_{50}]^{\frac{1}{6}} \qquad (50)$$

The hydraulic radius for grain resistance can then be estimated as:

$$R_g = R_b\left[\frac{n_g}{n_b}\right]^{\frac{3}{2}} \qquad (51)$$

where R_b is obtained from equation 48, and n_b is obtained from equation 45, subject to the constraints given by equations 46 and 47.

Table 5.5
Approximate hydraulic roughness coefficients for total and bank or wall roughness in natural, alluvial channels

Description of channel	Total n_T	Wall n_W
Upland streams		
Sand and gravel bed; bare, exposed banks.	0.030 - 0.040	0.030 - 0.045
Sand and gravel bed; exposed banks with vegetation; grass and weeds.	.035 - .045	.035 - .050
Sand and gravel bed, vegetated banks; grass and weeds, with some brush.	.040 - .048	.045 - .060
Wide, alluvial channels		
Sand bed; bare, exposed banks.	.025 - .035	.030 - .040
Sand bed, vegetated banks.	.030 - .040	.035 - .050
Gravel bed, vegetated banks.	.030 - >.040	.035 - >.050

Note--See table 5.4 for values of n_T. In natural alluvial channels, n_W is usually greater than n_T.

Effective Shear Stress for Sediment Transportation

The effective shear stress for sediment transportation is given by:

$$\tau = \gamma R_g S \qquad (52)$$

where:

τ = effective shear stress (lb/ft^2),
γ = specific weight of water (lb/ft^3),
R_g = hydraulic radius for grain resistance (ft), and
S = energy gradient, slope of the channel bed for normal flow.

The effective shear stress, given by equation 52, will be less than the total shear stress averaged over the cross section, $\tau_T = \gamma R_T S$, because some of the total available energy is expended on the banks due to bank roughness and because some is expended on the bed due to form roughness.

Piecewise Normal Approximation

Hydrographs in natural channels typically consist of a period of increasing discharge until the maximum, or peak discharge, is reached; a period of recession, or decreasing discharge from the peak; and then a longer period of gradually decreasing discharge. If the hydrograph is in an ephemeral stream, or if base flow is subtracted from the hydrograph, then the resulting flood hydrograph starts at zero, rises to the peak, and then returns to zero. Throughout this chapter, the term hydrograph refers to flood hydrographs of this type.

Double-Triangle Approximation

A continuous approximation to hydrographs is the double-triangle approximation, consisting of straight line segments between the points given by equations 26 through 33. The equation describing this standard, double-triangle hydrograph is:

$$q(t) = \begin{cases} \frac{Q_p}{t_p} t & 0 \leqq t \leqq t_p \\ \frac{9}{5} Q_p - \frac{4}{5} \frac{Q_p}{t_p} t & t_p \leqq t \leqq 2t_p \\ \frac{1}{3} Q_p - \frac{1}{15} \frac{Q_p}{t_p} t & 2t_p \leqq t \leqq 5t_p \end{cases} \qquad (53)$$

where:

$q(t)$ = runoff rate (in/h),
Q_p = peak runoff rate (in/h),
t_p = time to peak = D/5 (h),
t = time (h).

Piecewise Normal Approximation

The double-triangle hydrograph can be approximated by a series of step functions over the duration of flow. If normal flow is assumed (equations 38 and 40) during each interval on the stepwise approximation, the result is a piecewise normal hydrograph approximation. Let t_i be the dimensionless time to midpoint of an interval; let z_j be the length of the interval; and let u_i be the dimensionless ordinate for each interval. Using nine intervals and the double-triangle hydrograph described by equation 53, the dimensionless hydrograph described in table 5.6 results.

Table 5.6
Values of the dimensionless, piecewise approximating hydrograph for 9 intervals and the standard double-triangle hydrograph

Index (j)	Distance to interval midpoint (t_j)	Length of interval (z_j)	Dimensionless hydrograph ordinate (u_j)
1	0.050	0.10	0.250
2	.125	.05	.625
3	.175	.05	.875
4	.225	.05	.900
5	.275	.05	.700
6	.350	.10	.400
7	.500	.20	.167
8	.700	.20	.100
9	.900	.20	.033

If each z_j is multiplied by the effective duration, D, and each u_j is multiplied by the peak discharge, Q_p, the result will be a piecewise approximation to the double-triangle hydrograph, with duration equal to D and runoff volume equal to V. That is, the piecewise approximating hydrograph matches the given runoff volume and effective duration exactly and approximates the peak discharge as 0.9 Q_p. Each interval on the piecewise approximation has a length equal to z_j D and a discharge equal to u_j Q_p. Within each interval, flow is assumed to be normal (and thus satisfies equations 38 and 40 through a numerical approximation subroutine), and equations 38 through 40, 45, 48, 51, and 52 are solved to estimate the hydraulic variables for the sediment transport calculations.

One final hydrologic-hydraulic calculation routine is needed to describe flow in some stream channels. In ephemeral streams the storm runoff events are separated by periods of no flow. However, intermittent streams are often characterized by periods of baseflow between storm events. A logical extension of the channel routing procedures to calculate flow depths, and the resulting sediment transport capacity, is to calculate normal flow depth for each day during baseflow periods. The procedure is to calculate total volume of runoff, on a daily time step, for each day between runoff events. Division by D = 24 h and multiplication by C_5 = 1.0 in equation 35 results in an average daily flow rate. Given the average daily flow rate, equations 38-40, 45, 48, 51 and 52 are solved to estimate the hydraulic variables for the sediment transport calculations.

SEDIMENT TRANSPORT CALCULATIONS

Sediment transport is assumed to be equal to sediment transport capacity. If sediment load exceeds transport capacity, deposition occurs, and if transport capacity exceeds sediment load, scour or erosion may occur. However, for alluvial channels with noncohesive sediments, it is common to assume that sediment transport rate is equal to sediment transport capacity. To avoid more elaborate sediment-deposition models and channel-erosion models (Foster et al. 1981), we assume that, as a first approximation, sediment transport rate is equal to sediment transport capacity.

Because sediment transport capacity, or transport capacity, hereafter, is strongly related to localized in-channel processes, it is, in large part, determined by the hydraulic variables described earlier. Inasmuch as the in-channel features, such as channel morphology and sediment properties, as well as the hydrologic and hydraulic variables, reflect upland processes, these upland processes are reflected in the transport capacity calculations.

The Bed Load Equation

Following Einstein (1950) and others, a distinction is made between bed load and suspended load. If we assume that sediment transport rate is proportional to the water flow rate, then this distinction is somewhat arbitrary. This is because particles that travel as bed load at one flow rate may be suspended at another. The relationship between mode of transport and flow rate is a dynamically complex one and represents a continuous, rather than distinct, transition.

Nevertheless, it is reasonable to assume that the "larger" particles travel as bed load and that the "smaller" particles more easily enter suspension. Moreover, it is computationally convenient to assume a sharp distinction based on particle size. Therefore, we arbitrarily assume that all sediment larger than 0.062 mm in diameter is transported as bed load, and that finer material is transported as suspended load. Separate transport equations were derived for suspended load transport and bed load transport (of the bed material) based on this assumption.

Using a modification of the DuBoys-Straub formula (see Graf (1971) for a complete description), transport capacity for bed-load-sized particles can be computed as:

$$g_{sb}(d_i) = \alpha f_i B_s(d_i)\tau[\tau - \tau_c(d_i)] \tag{54}$$

where:

$g_{sb}(d_i)$ = transport capacity per unit width for particles of size d_i (lb/s-ft),
α = a weighting factor to ensure that the sum of the individual transport capacities equals the total transport capacity computed using the median particle size,
f_i = proportion of particles in size class i,
d_i = diameter of particles in size class i (mm),
$Bs(d_i)$ = sediment transport coefficient (ft^3/lb-s),
τ = effective shear stress (lb/ft^2), and
$\tau_c(d_i)$ = critical shear stress for particles in size class i (lb/ft^2).

Values of B_s and τ_c were determined by Straub (1935). The total bed load transport capacity is then found by summing the results from equation 54 over all size fractions.

However, values of B_s and τ_c, as developed by Straub (1935), were for total shear stress, rather than the effective shear stress, corresponding with grain resistance. For the effective shear stress, Lane (1982b) derived parameter estimates as:

$$B_s(d_i) = \frac{40.0}{d_i^{1.5}} \qquad (55)$$

and:

$$\tau_c(d_i) = \begin{cases} 0.0022 + 0.010\, d_i & 0.062 \leq d_i \leq 1.0 \\ -0.0078 + 0.020\, d_i & 1.0 < d_i \end{cases} \qquad (56)$$

where d_i is the representative particle diameter in millimeters. Equations 55 and 56 were calibrated with observed sediment transport data from the Niobrara River in Nebraska (Colby and Hembree 1955) for particle sizes up to 2.0 mm. Therefore, equations 55 and 56 have not been evaluated for particles larger than 2.0 mm in diameter. Because the weighting factor, α, in equation 54 ensures that the sum of the individual transport capacities equals the total transport capacity computed using the median particle size, d_{50}, in equations 54 through 56, the model has not been evaluated for values of d_{50} in excess of 1.0 mm.

The Suspended Load Equation

Bagnold (1956, 1966) proposed a sediment transport model based on the concept of stream power as:

$$i_s = P\,\frac{e_s\,u_s}{v_s}\,(1 - e_b) \qquad (57)$$

where:

- i_s = suspended sediment transport rate per unit width (lb/s-ft),
- P = τV = available stream power per unit area of the bed (lb/s-ft),
- e_s = suspended load efficiency factor,
- e_b = bed load efficiency factor,
- u_s = transport velocity of suspended load (ft/s), and
- v_s = settling velocity of the particles (ft/s).

Now, if u_s is assumed to be equal to the mean velocity of the fluid, V, then equation 57 is of the form:

$$g_{sus} = CAS\ f_{sc}\,\tau V^2 \qquad (58)$$

where:

- g_{sus} = suspended sediment transport capacity (lb/s-ft),
- f_{sc} = proportion of particles smaller than 0.062 mm in the channel bed material,
- τ = effective shear stress (lb/ft^2),
- V = average velocity (ft/s), and
- CAS = suspended sediment transport coefficient (s/ft).

The suspended sediment transport coefficient, CAS, incorporates the efficiency parameters and the settling velocity of the suspended particles. Values of CAS have been determined by calibration with observed data. However, because of the scarcity of observed data and the interaction of the efficiency parameters and settling velocity, and their interaction with flow dynamics, values of CAS are not well specified by measurable physical characteristics.

Calculation of Sediment Transport and Yield

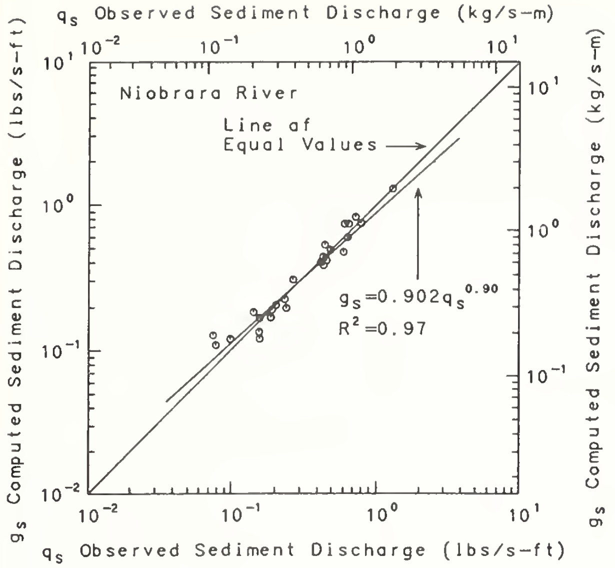
Typical applications of the sediment transport component of the model include predicting sediment discharge rates for steady flow and predicting sediment yields using the piecewise normal hydrograph approximation. The sediment transport model was fitted to data representing 27 observations at the Niobrara River in Nebraska, USA (Colby and Hembree 1955). These data represent nearly steady state conditions. Observed and computed sediment discharge rates are shown in figure 5.2A. The fitted and measured sediment discharge rates agree very well.

The sediment yield model, using the piecewise normal approximation, was used to predict sediment yields for 47 runoff events from five small watersheds in southern and southeastern Arizona. These small (4.0 to 10.0 acre) watersheds are described in more detail by Lane et al. (1978). Predicted and observed sediment yields for these watersheds are shown in figure 5.2B. Notice that there is more variation in the sediment yield data than in the sediment discharge data, and that the observed and computed data are in closer agreement when the model was calibrated (figure 5.2A) than when it was used to predict (figure 5.2B).

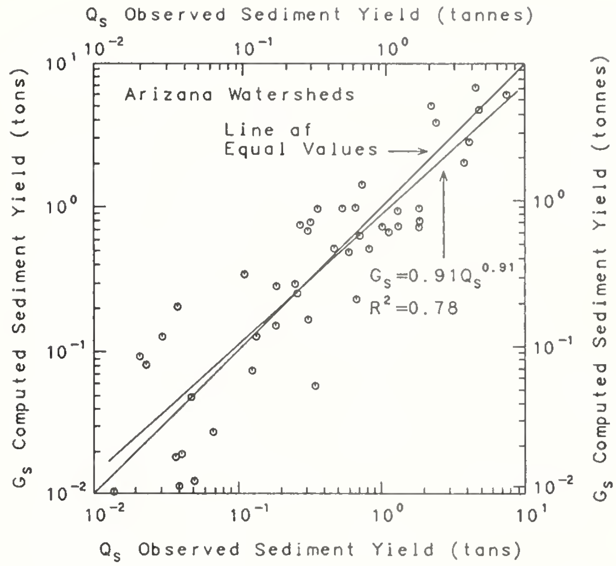
Parameter Estimation

Parameter estimation techniques are summarized in table 5.7 based on the sediment transport model summarized above, (Lane 1982a, 1982b and Lane and Hakonson 1981), the suspended-transport model (Bagnold 1956, 1966), open channel flow hydraulics (Chow 1959), and established sediment transport theory (Graf 1971).

The channel width is not the mean width used to represent average segment width in the transmission loss equations but is the actual channel width at the particular cross section where the sediment transport calculations are made. To meet the normal flow assumptions and the assumption that the channel bed material represents the sediment-size distribution available for transport, the cross section should be selected as representative of the assumptions and the particular channel reach. As much as possible, the representative cross section should reflect



A



B

Figure 5.2
Observed and computed sediment data for (A) Niobrara River and (B) the Arizona watersheds (from Lane 1982b).

a straight reach with uniform flow conditions, uniform channel slope and a representative distribution. The channel slope is the slope of the bed and should represent a uniform reach, as described above.

The sediment particle-size distribution (f_i, d_i) should represent the sediment available for transport at the particular cross section and should not be biased by nonrepresentative samples. Particles larger than those expected to be transported under anticipated flow conditions should not be included in samples used to compute particle-size distributions. The median particle size, d_{50}, is a critical parameter and should be based on a sufficient number of representative samples to accurately reflect the median size. The proportion of silt-clay in the bed material, f_{sc}, is an equally important parameter, subject to the same sampling restrictions. Moreover, high values of f_{sc} will result in unrealistic proportions of silt-clay particles in transport. As the proportion of silt-clay in the bed material, f_{sc}, exceeds a few percent, the character of the channel alluvium may change from noncohesive to cohesive and violate the model assumptions. In the absence of better information, the sediment model described herein should not be used if f_{sc} is greater than 0.10.

DISCUSSION AND SUMMARY

This chapter describes the development and application of a model to simulate hydrologic, hydraulic, and sedimentation processes in stream channels on rangeland watersheds. The model is simplified in that it approximates these processes. The complex processes of transmission losses are approximated through a linear differential equation, including length and width of the channel, effective hydraulic conductivity of the channel alluvium, and mean values of runoff volume and flow duration. All these runoff variables and hydrograph features are represented based on their average relation to the watershed and channel features, and the average relations are then used to compute values for individual runoff events.

Because average relationships are used, predictions for individual events may be in error, especially for the extreme events associated with very large or very small storms, and with unusual antecedent conditions. For example, flow duration is usually a function of antecedent conditions and storm size. However, the use of an average or representative flow duration is useful in predicting the expected value of transmission losses and in predicting average peak discharge-runoff volume relationships.

Runoff in natural stream channels is spatially varied and unsteady. These variations in space and time are approximated by the piecewise normal hydrograph approximation. Dynamic interactions between the flowing water and the channel bed and banks produce complex open-channel-flow relationships. These are approximated by considering bed, bank, and grain resistance to flow in channels with rectangular cross section. These simplifications, together with the assumption of piecewise normal flow, allow application of sediment transport equations to estimate sediment transport and yield.

Table 5.7
Parameters used in the sediment transport and sediment yield procedures

Parameter or variable	Range in values	Source of estimate and comments
Channel:		
Width w	> 0.0	Cross-section data. This width is not the mean reach width as used in the transmission loss equations; it is the actual width at the cross section of interest.
Slope s	> 0.0	Topographic map; field observations.
Sediment:		
Particle-size distribution (f_i, d_i)	$\Sigma f_i = 1 - f_{sc}$	Bed material samples. Distribution of bed sediments larger than 0.062 mm. Up to 10 size fractions.
d_{50}	$0.062 \leq d_{50} \leq 2.0$ mm	Bed material samples. Median particle size.
f_{sc}	$0.0 < f_{sc} \leq 0.10$	Bed material samples. Proportion of bed material finer than 0.062 mm. Values of $f_{sc} > 0.10$ may indicate cohesive material.
Hydraulics:		
Total roughness n_T	$0.012 - 0.048^+$	Tables 5.4 and 5.5; field observations.
Wall roughness n_W	$0.030 - 0.060^+$	Table 5.5; field observations.
Transport parameters:		
$B_s(d_i)$	> 0.0	Equation 55
$\tau_c(d_i)$	> 0.0028	Equation 56
CAS	1.0 - 10.0	Suspended-transport parameter. Complex function of particle dynamics. Estimate from calibration using observed data. Default value, corresponding to medium-sized silt, of CAS = 5.0 recommended in the absence of better estimates.

Particle sorting and enrichment process, as a result of selective erosion, transport, and deposition, are approximated by sediment transport equations for suspended particles and those up to 10 size fractions in the bed load size range. By including variations in discharge throughout the hydrograph, and variations in transport capacity through the range of particle sizes, the transport calculations approximate the particle sorting processes. Through use of the piecewise normal approximating hydrograph and the particle-size distribution for bed sediments, the sediment yield calculations approximate the influence of particle sorting processes upon sediment yield.

Given information from the upland component of the hydrologic model and characteristics of watershed channel system, information presented in this chapter can be used to estimate runoff and sediment yield from rangeland watersheds. Observed data can be used to determine parameter values or to improve the accuracy of their estimates. However, in the absence of observed data, the relationships presented in this chapter can be used to estimate the model parameters within the limitations described earlier.

Once the model is applied to a particular watershed channel system, it can be used, via simulation, to derive statistical relationships such as sediment rating curves, delivery ratios, and enrichment ratios. These relationships, in turn, can be used to predict sediment yield to characterize the particular watershed and to compare it with other watersheds.

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6. PLANT COMPONENT[1]

J.D. Hanson, J.W. Skiles, W.J. Parton

INTRODUCTION

Ecosystem simulation is primarily complicated by the system size and complexity and the lack of data for deriving parameters (Patten 1972). Models of varying resolution describing plant growth and development have been produced in the past decade. These models range in complexity from regression models (West and Lauenroth 1982) to extremely complex process models (Innis 1978, White 1984). Some models are based on a metaphor that considers the plant to be some physical or biochemical system, such as an enzymatic system (Thornley 1972, Thoughton 1977). Other models were developed using a systems modeling approach which makes them particularly useful in describing and synthesizing the conceptual structure of the system (Ares and Singh 1974). These models are often nonlinear and are based on some type of maximum reduction technique (Van Bavel et al. 1972, Connor et al. 1974, Reed et al. 1976, Gilmanov 1977, Cunningham and Reynolds 1978, Detling et al. 1979, Coughenour et al. 1984). Even though Patten (1972) argued that linear models behave more like ecosystems than do nonlinear ones, we think most physiological responses are nonlinear and, therefore, are more representative of plant systems.

Model resolution is also an important consideration when simulating plant growth and development. Particularly important is whether to include a complex description of photosynthesis, respiration, and carbon allocation. Two rather highly resolved plant growth models (Reynolds et al. 1980, Jones et al. 1980) present similar philosophies; they are driven by photosythesis and subsequently partition assimilated carbon into plant organs. Hesketh and Jones (1980) stated the importance of basing plant-growth and -yield models on photosynthesis so that the effects of various policies on plant production, the economy, and the environment can be studied. Thus, it seems very important to include a detailed description of the carbon assimilation and allocation aspects of plant development in plant growth models. This philosophy naturally leads to the inclusion of belowground dynamics as well.

MODEL OBJECTIVES

The primary producer model described here was developed as a component of the general rangeland model, SPUR (Simulation of Production and Utilization of Rangelands). The plant model simulates carbon and nitrogen flows through green shoots, seeds, live roots and crowns, litter, dead roots, and soil components of rangeland ecosystems in response to various environmental variables. The specific objectives of the modeling effort are to (1) develop a model that predicts, by species or species group, the daily biomass and nitrogen content of green and dead rangeland vegetation; (2) include in the model structure the framework to simulate spatial heterogeneity of range communities by estimating multiple points along several catenae; (3) minimize data input necessary to operate the model, thereby making it useful on several types of western rangeland; and (4) develop the model so that it can aid in making practical management decisions based on the response of vegetation to the environment. This final objective includes the response of vegetation to herbivory, nitrogen availability, and water availability.

MODEL OVERVIEW

The Ecosystem Level Model (ELM), developed by the U.S. Grassland Biome Study (Innis 1978), and grassland models developed by Parton et al. (1978) and Detling et al. (1978, 1979) were studied extensively during the construction of this model. The newly developed model is unique because (1) it is a multipoint model that is capable of simultaneously simulating nine sites; (2) it is designed to allow competition for water and nutrients between different species or species groups; and (3) it allows herbivory and includes the effects of animal trampling. The model simulates the flow of carbon, assuming phytomass is 40 percent carbon, and nitrogen through the soil-plant-animal interface. There are seven carbon and eight nitrogen state variables in the model (fig. 6.1). In the flow diagram, seven compartments are divided into two separate components to emphasize the concomitant existence of carbon and nitrogen within the state variables. Species-dependent state variables in the carbon and nitrogen submodels are green shoots, live roots, propagules, and standing dead. Dead roots, litter, soil inorganic nitrogen, and soil organic matter are shown independent of species identity.

Abiotic variables used by the plant growth model include daily minimum and maximum air and soil temperature, precipitation, soil water potential, daily solar radiation, accumulated wind run, and soil bulk density. The model adequately simulated single and multiple species rangeland production for northeastern Colorado prairie (Skiles et al. 1982, Hanson et al. 1983).

Process rates in the model are calculated by reducing maximum rates by nondimensional scalar multipliers ranging from 0 to 1. The shape of the response surfaces for the various processes was obtained from the literature or by deducing the expected effect. This technique may, however, lead to over-reduction of some processes when several controlling factors are suboptimal (Detling et al. 1978). The functions used to

[1]This report was adapted from J.D. Hanson, J.W. Skiles, and W.J. Parton, "A Multispecies Model for Spatially Heterogeneous Rangeland Plant Communities," submitted to Ecological Modelling.

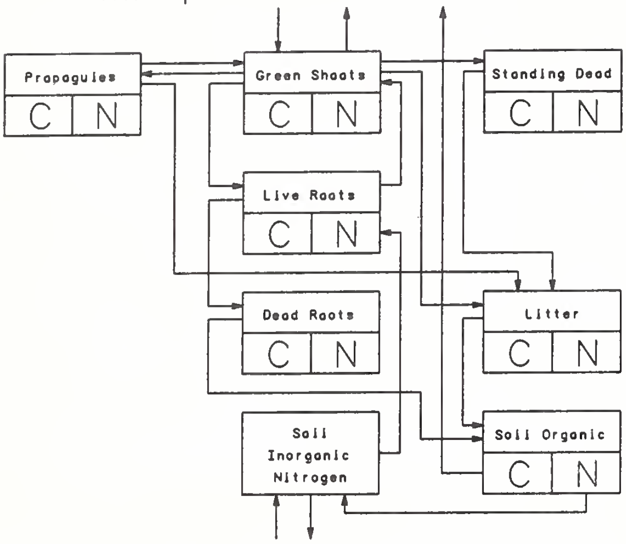

Figure 6.1
Flow diagram of carbon (C) and nitrogen (N) for rangeland plant growth model.

develop these response curves are ATANF, BELL, HYP, and THRESH; whenever possible the parameters of these functions were derived from actual data.

The FUNCTION ATANF is used for soil-water-potential response curves (Parton and Innis 1972). The curve is sigmoidal but does not need to have a y-intercept at zero or an asymptote at y=1 (fig. 6.2A). The functional form is:

$$\mathrm{ATANF}(a,b,c,d,x) = b + \frac{c}{\pi}\tan^{-1}[\pi d(x-a)] \qquad (1)$$

where for dependent variable x, a and b are the x,y coordinates, respectively, at the inflection point; c is the distance from the maximum to the minimum point along the y-axis; and d is the slope of the line at the inflection point. The FUNCTION BELL is an equation similar to that used by Reed et al. (1976) and Gilmanov (1974) for relating temperature to various physiological processes (fig. 6.2B). Within the same species, process rates can vary depending on whether soil or ambient temperature is input to the function. The function is:

$$\mathrm{BELL}(S,TC) =$$

$$\left[\left(\frac{P_{3,S}-TC}{P_{3,S}-P_{4,S}}\right)\left(\frac{TC-P_{5,S}}{P_{4,S}-P_{5,S}}\right)^{\left(\frac{P_{4,S}-P_{5,S}}{P_{3,S}-P_{4,S}}\right)}\right]^{z} \qquad (2)$$

where TC is the temperature; S is the species; $P_{3,S}$, $P_{4,S}$, and $P_{5,S}$ are maximum, optimum, and minimum temperatures at which activity occurs for species S; and z = 1.328 is the shape parameter for the curve (Detling et al. 1978). The FUNCTION HYP is a rectangular hyperbola (fig. 6.2C). The function, used throughout the model, has the form:

$$\mathrm{HYP}(k,x) = 1 - e^{-kx} \qquad (3)$$

where x is the independent variable, and k is the species-specific parameter. The FUNCTION THRESH, a threshold response curve (fig. 6.2D), has the formulation:

$$\mathrm{THRESH}(k,n,x) = \frac{1}{1+\left(\frac{x}{k}\right)^{n}} \qquad (4)$$

where n is the threshold tolerance, and k is the value of the independent variable x when THRESH is 0.5.

ASSUMPTIONS

The principal assumptions made during development of this primary producer model are given below. Secondary assumptions are mentioned as they arise during discussion of the model.

1. Cool-season (C_3) and warm-season (C_4) plants are similar in their response to a changing environment, therefore, the same functional relationships with different parameters can be used to model processes within species of either category. Crassulacean Acid Metabolism (CAM) plants were not included in this effort.

2. Rangeland plant species compete for nutrients and water. Nitrogen is the primary limiting nutrient on rangeland (Wilson 1975, Detling et al. 1979). Space is not considered to be limiting.

3. Range plants are generally low growing and the leaves tend to be narrow, thus light is equally available to all species and all photosynthetic tissues within species. This assumption is not acceptable in forest or shrub-dominated systems, and a light absorption algorithm (Waggoner 1969, Idso and DeWitt 1970) will need to be included in the model for these situations.

4. All plants have an equal priority to accumulate soil nitrogen, but plants with large amounts of live root biomass have a higher proportion of nitrogen available to them than plants with less root biomass. Thus, available nitrogen is partitioned by species according to root biomass and the present nitrogen demand.

5. Plants are primarily composed of carbohydrates that have a molecular formula of the form $(CH_2O)x$. Therefore, we assume plant biomass is 40 percent carbon.

6. The woody portion of perennial plants is standing dead biomass.

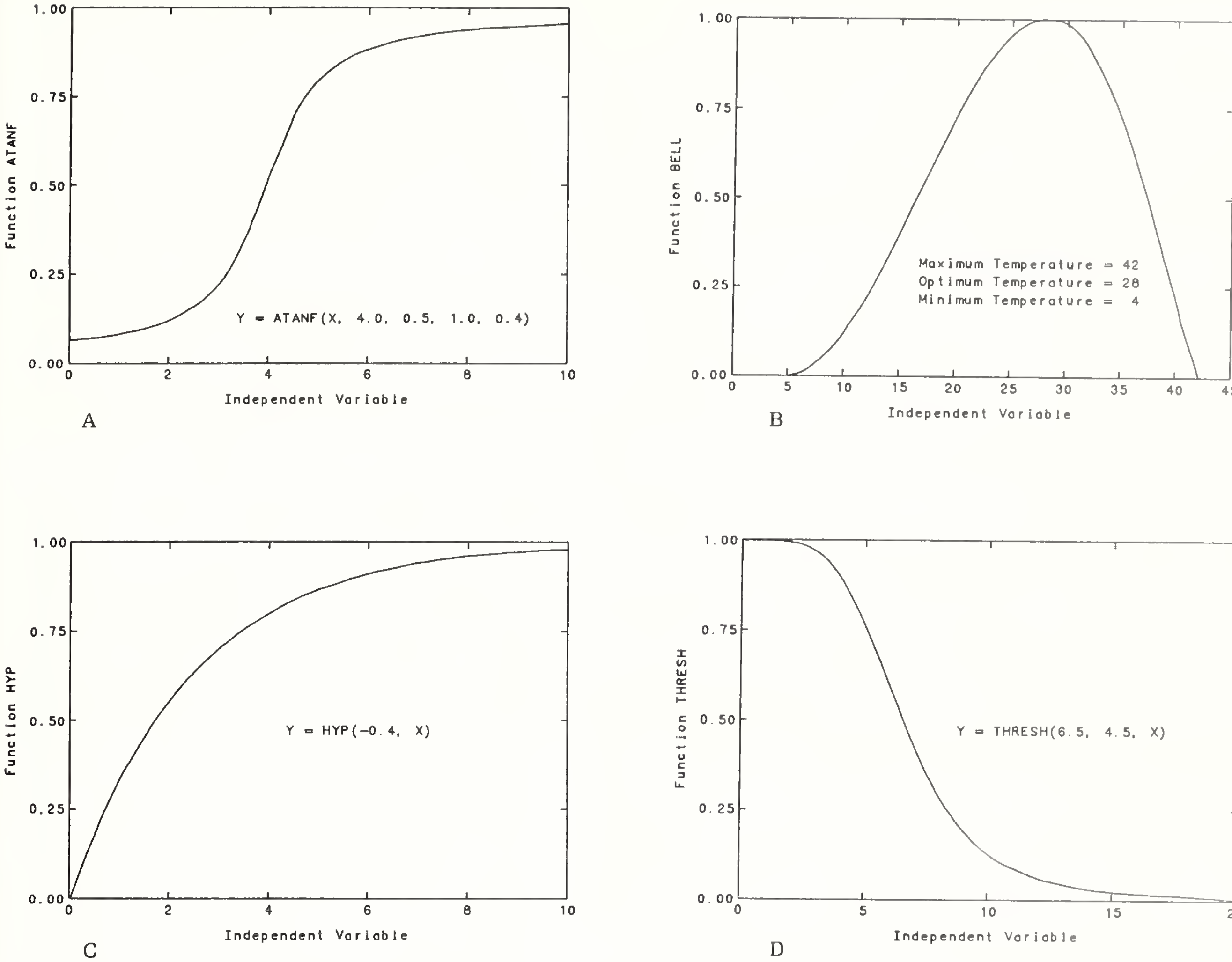

Figure 6.2 A-D
Controlling functions of plant growth model: A, FUNCTION ATANF; B, standard bell curve (BELL); C, rectangular hyperbola (HYP); and D, threshold response curve (THRESH).

MODEL DESCRIPTION

Some leaf area must exist to initiate carbon assimilation. The phytomass needed for aboveground development can come from two sources. When the environmental conditions are proper, phytomass is translocated from perennial roots to shoots. Roots can support only a limited amount of aboveground green phytomass, therefore, upward translocation stops when a critical root:shoot ratio is reached. Also, initial leaf area can result from seed germination. In western grasslands this source of aboveground phytomass is of lesser importance for perennials than for annuals. The phytomass of germinating seeds is also partitioned into roots and shoots at a proportion dependent on the same critical root:shoot ratio.

Once upward translocation or seed germination establishes some aboveground green material, carbon assimilation begins. Diurnal net photosynthetic patterns are generated for each species throughout the day. Total daily net carbon assimilation is subsequently determined by integrating net photosynthesis over the photoperiod.

Phytomass can be translocated from the shoots to either the roots or propagules. Translocation from the shoots to the roots must maintain the root:shoot ratio. Thus, if the shoot phytomass becomes too great for the roots to maintain, a portion of the shoot phytomass is shunted to the roots. Also, when senescence begins, a larger proportion of the new photosynthate is sent below ground. Translocation from the shoots to the propagules is proportional to the total daily net

photosynthetic rate. Shoot and root mortality and respiration are controlled by soil-water potential and temperature. Shoot respiration is calculated only at night because daytime respiration is included in the calculation of net carbon assimilation rate. Seed mortality is a proportion of the propagule phytomass; seeds are not considered to be affected by temperature or water stress.

Herbivores affect the amount of standing green and dead phytomass by eating or trampling the vegetation. The plant production model is concerned only with the trampling effects of domestic and wild herbivores. All standing live and dead material is available to be trampled, but standing dead is considered to be less resilient than standing green. Also, herbivory does not explicitly act as a stimulant for plant growth. But, if herbivores reduce plant biomass substantially, translocation from roots to shoots can again be initiated. A herbivore model is responsible for returning organic matter and inorganic nitrogen to the plant model via excreta.

Decomposition of dead roots, litter, and soil organic matter occurs only if soil inorganic nitrogen is present in the system. Maximum decomposition rate is determined as a proportion of the respective pool; the multiplicative effects of temperature and soil-water potential subsequently reduce that rate.

Standard saturation kinetics are used to estimate the nitrogen uptake rate. Thus, the theoretical maximum nitrogen uptake rate and the nitrogen-use efficiency coefficient control interspecific competition for nitrogen. If there is not enough inorganic nitrogen in the soil to satisfy the requirements of all species, then nitrogen is partitioned in proportion to each species demand.

Nitrogen transfer from roots to shoots is probably the most critical calculation of the plant model. The flow rate into the shoot directly influences photosynthesis, thereby, controlling plant growth. Also, this flow controls the C:N ratio for the aboveground plant and thus affects forage quality and diets of grazing herbivores. This approach is very similar to that used in the ELM model (Reuss and Innis 1977).

In general, when carbon flows from one pool to another, nitrogen is sent at a rate equivalent to the C:N ratio of the donor pool. For example, when cattle trample standing live phytomass, the phytomass going to the litter pool has the same C:N ratio as the standing live phytomass. There are, however, several exceptions to this rule. First, when shoots die because of senescence, the plant "attempts" to conserve nitrogen, so the C:N ratio is lowest in the most senescent tissue. Another exception occurs in the propagule dynamics. For seed production, mortality and germination, the C:N ratio is held constant. Finally, the model allows leaching to occur from standing dead material.

Dead root and litter decomposition cause a nitrogen transfer to the organic pool at the C:N ratio of the respective donor. Dinitrogen (N_2) is fixed as soil inorganic nitrogen in proportion to precipitation. Nitrogen is mineralized at a rate necessary to maintain a constant soil organic C:N ratio. Soil-water potential and soil inorganic-nitrogen concentration control denitrification rates. The amount of inorganic nitrogen immobilized by the decomposition of litter and dead roots is calculated as the difference between the nitrogen needed to maintain a C:N ratio of 10 in the organic matter and the nitrogen released by the decomposition of dead roots and litter.

Carbon Flows

Growth Initiation

Transfer from roots to shoots. Aboveground green biomass of perennial plants can be transferred from roots to shoots either in the spring or after some process has removed a critical amount of green biomass. For carbon to be transferred, the following three conditions must be met.

$$T10 > CRIT_{3,S}$$

$$W5_j > CRIT_{4,S}$$

$$P_{9,S}\ PHYTM_{1,S} < PHYTM_{2,S}$$

where T10 and $W5_J$ are the average 10-day soil temperature and 5-day soil-water potential for site j, respectively; S is the species, and the other terms are defined in tables 6.1 and 6.2. These conditions assure that the temperature and water conditions are appropriate for root-to-shoot carbon translocation, and that adequate root biomass is available to support additional aboveground material. If these conditions are met, carbon is transferred from the roots to the shoots at a rate of:

$$TRS = P_{18,S}\ PHYTM_{2,S} \tag{5}$$

where TRS is the transfer rate from roots to shoots; otherwise TRS = 0.0. The value of $P_{18,S}$ is the proportion of root biomass translocated to the shoots for species S.

Germination. In annuals or perennials, new biomass can come from germinating seeds. Germination occurs when:

$$W15 > CRIT_{5,S}$$

and:

$$T10 > CRIT_{3,S}$$

where W15 is the soil-water potential for the top 15 cm of the soil profile. The germination rate when these conditions are met is:

$$GERM = P_{19,S}\ PHYTM_{3,S}\ ETG \tag{6}$$

where the maximum percent germination is reduced depending on the temperature effect. The temperature effect on germination, ETG, is calculated from the standard bell curve (eq. 2)

Table 6.1.
List of species-specific parameters $P_{i,S}$ and critical values ($CRIT_{i,S}$) for species S, and nonspecies-, nonsite specific-parameters (PNS_j) for site j of the SPUR plant component

	Definition	Unit
	P Matrix	
1	Theoretical maximum net photosynthetic rate	mg dm^{-2} h^{-1}
2	Light-use efficiency coefficient	m^2 W^{-1}
3	Maximum temperature for positive plant activity	°C
4	Optimum temperature for positive plant activity	°C
5	Minimum temperature for positive plant activity	°C
6	Water potential at which photosynthetic activity is one-half maximum	-bars
7	Drought tolerance coefficient	NOD[1/]
8	Proportion of photosynthate translocated to roots after senescence begins	NOD
9	Maximum root-to-shoot ratio	NOD
10	Wind-tolerance coefficient (standing dead)	km^{-1}
11	Precipitation-tolerance coefficient (standing dead)	cm^{-1}
12	Proportion of phytomass susceptible to trampling	NOD
13	Susceptibility of standing dead to trampling	ha an^{-1}
14	Susceptibility of green shoots to trampling	ha an^{-1}
15	Proportion of green shoots susceptible to death	NOD
16	Phytomass to leaf area conversion factor	m^2 g^{-1}
17	Proportion of photosynthate translocated to propagules after flower initiation	NOD
18	Proportion of root phytomass translocated to shoots	NOD
19	Germination proportion	NOD
20	Maintenance-respiration coefficient	mg g^{-1} day^{-1}
21	Proportion additional shoot death after senescence	NOD
22	NOT USED	
23	Seed-mortality proportion	NOD
24	Root-respiration proportion	NOD
25	Root-mortality proportion	NOD
26	Minimum percentage nitrogen for photosynthesis	NOD
27	Photosynthetic efficiency controlled by plant nitrogen	NOD
28	Maximum-nitrogen-uptake coefficient	g N g^{-1} day^{-1}
29	Nitrogen-use efficiency coefficient	m^2 g^{-1}
	CRIT Matrix	
1	Maximum leaf area index of green shoots	NOD
2	Temperature for frost kill	°C
3	Temperature for root to shoot translocation (TRS)	°C
4	Water potential for TRS	bars
5	Water potential for seed germination	bars
6	Julian day that seed production begins	NOD
7	Julian day that senescence begins	NOD
8	Julian day that senescence ends	NOD
	PNS Vector	
1	Proportion of dead roots susceptible to decomposition	NOD
2	Proportion of litter susceptible to decomposition	NOD
3	Proportion of organic matter susceptible to decomposition	NOD
4	Moisture tolerance of denitrification	-bars
5	Water potential at which decomposition activity is one-half maximum	-bars
6	Drought-tolerance coefficient for decomposition	NOD

[1/] NOD means nondimensional.

photosynthetic rate. Shoot and root mortality and respiration are controlled by soil-water potential and temperature. Shoot respiration is calculated only at night because daytime respiration is included in the calculation of net carbon assimilation rate. Seed mortality is a proportion of the propagule phytomass; seeds are not considered to be affected by temperature or water stress.

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$$TRS = P_{18,S}\ PHYTM_{2,S} \tag{5}$$

where TRS is the transfer rate from roots to shoots; otherwise TRS = 0.0. The value of $P_{18,S}$ is the proportion of root biomass translocated to the shoots for species S.

Germination. In annuals or perennials, new biomass can come from germinating seeds. Germination occurs when:

$$W15 > CRIT_{5,S}$$

and:

$$T10 > CRIT_{3,S}$$

where W15 is the soil-water potential for the top 15 cm of the soil profile. The germination rate when these conditions are met is:

$$GERM = P_{19,S}\ PHYTM_{3,S}\ ETG \tag{6}$$

where the maximum percent germination is reduced depending on the temperature effect. The temperature effect on germination, ETG, is calculated from the standard bell curve (eq. 2)

Table 6.1.
List of species-specific parameters $P_{i,S}$ and critical values ($CRIT_{i,S}$) for species S, and nonspecies-, nonsite specific-parameters (PNS_j) for site j of the SPUR plant component

	Definition	Unit
	P Matrix	
1	Theoretical maximum net photosynthetic rate	mg dm^{-2} h^{-1}
2	Light-use efficiency coefficient	m^2 W^{-1}
3	Maximum temperature for positive plant activity	°C
4	Optimum temperature for positive plant activity	°C
5	Minimum temperature for positive plant activity	°C
6	Water potential at which photosynthetic activity is one-half maximum	-bars
7	Drought tolerance coefficient	NOD[1/]
8	Proportion of photosynthate translocated to roots after senescence begins	NOD
9	Maximum root-to-shoot ratio	NOD
10	Wind-tolerance coefficient (standing dead)	km^{-1}
11	Precipitation-tolerance coefficient (standing dead)	cm^{-1}
12	Proportion of phytomass susceptible to trampling	NOD
13	Susceptibility of standing dead to trampling	ha an^{-1}
14	Susceptibility of green shoots to trampling	ha an^{-1}
15	Proportion of green shoots susceptible to death	NOD
16	Phytomass to leaf area conversion factor	m^2 g^{-1}
17	Proportion of photosynthate translocated to propagules after flower initiation	NOD
18	Proportion of root phytomass translocated to shoots	NOD
19	Germination proportion	NOD
20	Maintenance-respiration coefficient	mg g^{-1} day^{-1}
21	Proportion additional shoot death after senescence	NOD
22	NOT USED	
23	Seed-mortality proportion	NOD
24	Root-respiration proportion	NOD
25	Root-mortality proportion	NOD
26	Minimum percentage nitrogen for photosynthesis	NOD
27	Photosynthetic efficiency controlled by plant nitrogen	NOD
28	Maximum-nitrogen-uptake coefficient	g N g^{-1} day^{-1}
29	Nitrogen-use efficiency coefficient	m^2 g^{-1}
	CRIT Matrix	
1	Maximum leaf area index of green shoots	NOD
2	Temperature for frost kill	°C
3	Temperature for root to shoot translocation (TRS)	°C
4	Water potential for TRS	bars
5	Water potential for seed germination	bars
6	Julian day that seed production begins	NOD
7	Julian day that senescence begins	NOD
8	Julian day that senescence ends	NOD
	PNS Vector	
1	Proportion of dead roots susceptible to decomposition	NOD
2	Proportion of litter susceptible to decomposition	NOD
3	Proportion of organic matter susceptible to decomposition	NOD
4	Moisture tolerance of denitrification	-bars
5	Water potential at which decomposition activity is one-half maximum	-bars
6	Drought-tolerance coefficient for decomposition	NOD

[1/] NOD means nondimensional.

Table 6.2
Biomass and nitrogen state variables for site j of the rangeland plant growth model (units are g m^{-2})

Variable name	Definition	Variable name	Definition
	Biomass		
$PHYTM_{1,S}$	Green shoots	$DROOTS_j$	Dead roots
$PHYTM_{2,S}$	Live roots	$ALIT_j$	Litter
$PHYTM_{3,S}$	Propagules	$AORG_j$	Soil organic matter
$PHYTM_{4,S}$	Standing dead		
	Nitrogen		
$PNC_{1,S}$	Green shoot N	$DROOTN_j$	Dead root N
$PNC_{2,S}$	Live root N	$ALITN_j$	Litter N
$PNC_{3,S}$	Propagule N	$AORGN_j$	Soil organic N
$PNC_{4,S}$	Standing dead N	$SNIO_j$	Soil inorganic N

using the daily mean soil temperature. Subsequently, GERM is partitioned between roots and shoots. Knowing the maximum root:shoot ratio equals $P_{9,S}$ and the amount of biomass apportioned to the shoots is the total germinating biomass minus the biomass sent to the roots, then:

$$P_{9,S} = \frac{ROOTG}{GERM - ROOTG} \tag{7}$$

and solving for ROOTG and SHOOTG:

$$ROOTG = \frac{P_{9,S}\ GERM}{1 + P_{9,S}} \tag{8}$$

$$SHOOTG = GERM - ROOTG \tag{9}$$

where ROOTG and SHOOTG are the amount of biomass designated for roots and shoots, respectively.

Leaf area. When the aboveground green biomass compartment contains some biomass, the leaf area (LA) is defined as:

$$LA = \min\left[\begin{matrix} P_{16,S}\ PHYTM_{1,S} \\ CRIT_{1,S} \end{matrix}\right] \tag{10}$$

Carbon Assimilation

The basis for accumulating new plant biomass is photosynthesis. Diurnal patterns of net carbon dioxide assimilation rate are generated and subsequently integrated using Simpson's Rule with eight intervals which exceeds the minimum of four recommended by Detling et al. (1979) needed to preserve overall seasonal accuracy of the predictions. To generate these diurnal patterns, the time of sunrise must first be determined. Photoperiod (PP) is calculated using the methods of Parton and Logan (1981). Then assuming solar radiation peaks at 1200 hours, sunrise (SUNUP) can be determined as:

$$SUNUP = 12 - \frac{PP}{2} \tag{11}$$

and the interval of integration (HINC) is:

$$HINC = \frac{PP}{N} \tag{12}$$

where N is the number of integration intervals. The other environmental variable which needs to be calculated is the peak radiation during the day. Assuming peak solar radiation occurs at noon, maximum daily solar radiation (RMAX) can be calculated using the following algorithm. Assume light is distributed evenly throughout the day, then u = SUNUP and d = SUNUP + PP. Total daily radiation (RTOTAL) is:

$$RTOTAL = \int_u^d S(t)\,dt \tag{13}$$

where S(t) is the radiation at time t. Then applying the assumption of even light distribution and using a sine curve to approximate this distribution:

$$RTOTAL = RMAX \int_u^d \sin\left[\frac{\pi}{PP}(t - u)\right] dt \tag{14}$$

Integrating this function gives:

$$RTOTAL = 2\ RMAX\ \frac{PP}{\pi} \tag{15}$$

Finally, solving for RMAX:

$$RMAX = \frac{\pi}{2}\ \frac{RTOTAL}{PP} \tag{16}$$

and:

$$S(t) = RMAX \sin\left[\frac{\pi}{PP}(t - u)\right] \tag{17}$$

Photosynthetically active radiation, PAR, (W m^{-2}) is used to estimate net assimilation rate from the light-response curve (fig. 6.3). Since RTOTAL is calculated in langleys, S(t) in watts per square meter must be multiplied by 11.645 to convert to PAR. The actual amount of net carbon assimilation occurring at any point in time can now be determined. In the model, nitrogen, available water, temperature, leaf age, and light control net photosynthetic rate.

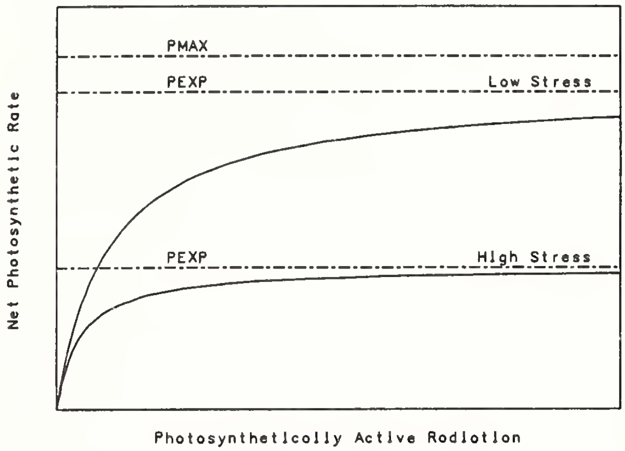

Figure 6.3
The effect of environmental stress on a typical light use efficiency curve for estimating photosynthesis.

Nitrogen. Data from Wilson (1975) show that the percentage shoot nitrogen of a C_4 grass falls no lower than about 1 percent. This leads to the conclusion that there is a lower bound to the species shoot nitrogen. We assume that if nitrogen falls below this percentage, the plant is unable to assimilate carbon. We calculate the distance from the present and the lower bound percentage shoot nitrogen as:

$$\mathrm{SPECTN} = \frac{P_{1,S}}{\mathrm{PHYTM}_{1,S}} - P_{26,S} \qquad (18)$$

where $P_{26,S}$ is the lower bound of percentage shoot nitrogen in the leaf, and $PNC_{1,S}$ is the present plant nitrogen content. Then, using FUNCTION HYP, the effect of nitrogen on photosynthesis (ENP) is:

$$\mathrm{ENP} = \begin{cases} \mathrm{HYP}(P_{27,S}, \mathrm{SPCTN}) & \mathrm{SPCTN} > 0 \\ 0 & \text{otherwise} \end{cases} \qquad (19)$$

This response curve is like that of Detling et al. (1979) except that it is smooth continuous rather than piecewise linear (fig. 6.4).

Soil moisture. Though using leaf-water potentials to describe photosynthesis is perhaps more mechanistically pleasing, the model does not include such an algorithm. Instead, soil water, in the wettest layer in which there are roots, is used to control photosynthesis. Sala et al. (1981) showed that in a shortgrass system, predawn leaf-water potentials were highly correlated with water potentials of the wettest layer. Thus, the assumption that net photosynthesis can be controlled by soil-water potential is at least a tenable alternative. The effect of soil moisture on photosynthesis (EMP) is subsequently computed as:

$$\mathrm{EMP} = \mathrm{THRESH}(P_{6,S}, P_{7,S}, -\mathrm{SWAT}) \qquad (20)$$

where SWAT is the soil-water potential of the wettest soil layer containing roots.

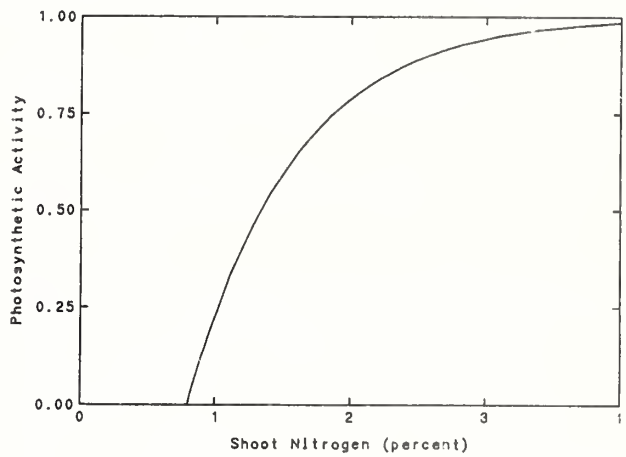

Figure 6.4
The effect of percent shoot nitrogen on photosynthetic activity.

Temperature. As mentioned previously, diurnal patterns of net photosynthesis must be generated. We have no way of determining the diurnal patterns of nitrogen or soil water within the model. However, by incorporating a diurnal temperature model (Parton and Logan 1981), ambient temperature is generated for each time photosynthesis is calculated during the day. The effect of ambient temperature on photosynthesis at time t [ETP(t)] is determined using FUNCTION BELL.

Leaf age. The effect of leaf age on net photosynthesis is included in the model to mimic late-season regrowth. This effect is incorporated by reducing the photosynthetic efficiency of the plants after senescence begins; we allow the maximum photosynthetic rate to be decreased to 25 percent of maximum as leaves age. The actual time senescence begins ($CRIT_{7,S}$) and its completion time ($CRIT_{8,S}$) are input as Julian calendar days. So, the effect of leaf age on photosynthesis (EAP) is:

$$\mathrm{EAP} = \begin{cases} 1 & \mathrm{DAY} < \mathrm{CRIT}_{7,S} \\ 0.25 & \mathrm{DAY} > \mathrm{CRIT}_{8,S} \\ 0.25 + 0.75\,\dfrac{\mathrm{CRIT}_{8,S} - \mathrm{DAY}}{\mathrm{CRIT}_{8,S} - \mathrm{CRIT}_{7,S}} & \text{otherwise} \end{cases} \qquad (21)$$

where DAY is the Julian day being simulated. Maximum net assimilation rate (PMAX) is subsequently determined by:

$$PMAX = P_{1,S}\ EAP \qquad (22)$$

Solar radiation. The solar radiation at time t (S(t)) was derived earlier. The expected photosynthetic rate at S(t) ($PEXP_S(t)$) is calculated from the relationship:

$$PEXP_{s(t)} = P_{2,S}\ PMAX \frac{S(t)}{PMAX + P_{2,S}\ S(t)} \qquad (23)$$

Daily net assimilation rate. The carbon dioxide assimilation rate for time t is subsequently estimated as:

$$PEXP(t) = PEXP_{s(t)}\ ENP\ EMP\ ETP(t) \qquad (24)$$

Daily net assimilation rate (PN) is then described as:

$$PN = 0.06823\ LA \int_u^d PEXP(t)\ dt \qquad (25)$$

where 0.06823 is a conversion factor which is the weight of one gram atom of C divided by the weight of one gram atom of CO_2 multiplied by 2.5, the ratio of phytomass to carbon, all multiplied by 0.1 to convert from dm^2 to m^2.

Translocation

According to the modeling framework, translocation within the plant can occur along three pathways. Assimilated carbohydrates can be shunted from roots to shoots, from shoots to roots, or from shoots to propagules. The first process was discussed earlier and is primarily involved with growth initiation. The second of these flows is calculated after all other losses and gains from the roots and shoots have been determined. A balance between roots and shoots is maintained according to the root:shoot ratio, $P_{9,S}$. Excess amount of biomass (B_X) in the shoots is determined as:

$$B_X = P_{9,S}\ PHYTM_{1,S} - PHYTM_{2,S} \qquad (26)$$

If there is more aboveground biomass than the roots can maintain, then B_X is greater than zero and biomass flows from the shoots to the roots, but if there is adequate root biomass to support more shoot biomass, then B_X is less than zero and translocation goes from roots to shoots. The shoot-to-root transfer described here is done only if B_X is greater than zero; otherwise TSR = 0 and TRS is calculated as a function of abiotic variables. The actual amount of biomass transported is calculated so the root:shoot ratio is maintained from one day to the next. Thus:

$$P_{9,S} = \frac{PHYTM_{2,S} + TSR}{PHYTM_{1,S} - TSR} \qquad (27)$$

since $P_{9,S}$ is a given value, TSR can be determined as:

$$TSR_0 = \frac{P_{9,S}\ PHYTM_{1,S} - PHYTM_{2,S}}{1 + P_{9,S}} = \frac{B_X}{1 + P_{9,S}} \qquad (28)$$

where TSR is the translocation from shoots to roots. This function assures there is no more aboveground phytomass than the present root biomass can support. Photosynthate is translocated directly to the roots after senescence of perennial plants begins. This is computed by the function:

$$TSR = \begin{cases} TSR_0 & DAY < CRIT_{7,S} \\ TSR_0 + P_{8,S}\ PN & \text{otherwise} \end{cases} \qquad (29)$$

where $CRIT_{7,S}$ is the day senescence begins and PN is the amount of new assimilate per simulated day.

Translocation of new photosynthate to seed production (TSP) occurs at the rate:

$$TSP = \begin{cases} 0 & DAY < CRIT_{6,S} \\ P_{17,S}\ PN & \text{otherwise} \end{cases} \qquad (30)$$

where $CRIT_{6,S}$ is the Julian day that seed production begins.

Respiration and Mortality

Shoots. Only nighttime shoot maintenance respiration must be calculated because net assimilation (PN) implicitly includes daytime respiration. This approach is used because measurements of *in situ* photosynthesis estimate net rather than gross photosynthesis. Very little information has been collected for dark respiration rates of range species; we, therefore, use a simplified version of the theory developed by Detling et al. (1978). We assume the carbon already fixed by the plant is structurally stable, and thus, energy is primarily used to allocate recent photosynthate. This simplification allows temperature and moisture stress to affect respiration in exactly the same way they affect net photosynthesis. Thus, total expected daily shoot maintenance respiration (TOTRES) occurs at a rate of:

$$TOTRES = 0.001\ P_{20,S}\ PN \qquad (31)$$

where $P_{20,S}$ is the maintenance-respiration coefficient (Hesketh and Jones 1980) and 0.001 is a conversion coefficient to change from grams to milligrams. Subsequently, night time respiration rate (RESP) is scaled to include only night time hours. Therefore:

$$RESP = TOTRES\ LA \left(\frac{24 - PP}{24}\right) \qquad (32)$$

Shoot mortality is a function of soil-water potential of the top 15 cm, minimum daily temperature, time of year, and the phytomass of live shoots. Water-stress-induced shoot death occurs

at the rate:

$$DS_1 = P_{15,S}\ PHYTM_{1,S}\ [1 - THRESH(22.1643,\ 5.5801,\ -W15)] \quad (33)$$

where the THRESH parameters were derived from Detling's "km" function (Detling et al. 1979). For simplicity, we allow shoots to die only at low temperatures and after senescence begins according to the computations:

$$DS_2 = \begin{cases} 0.1\ PHYTM_{1,S} & TMIN < CRIT_{2,S} \\ 0 & \text{otherwise} \end{cases} \quad (34)$$

$$DS_3 = \begin{cases} 0.01\ PHYTM_{1,S} & DAY > CRIT_{7,S} \\ 0 & \text{otherwise} \end{cases} \quad (35)$$

$$DS_4 = \begin{cases} P_{21,S}\ PHYTM_{1,S} & DAY > CRIT_{8,S} \\ 0 & \text{otherwise} \end{cases} \quad (36)$$

where TMIN is the minimum daily air temperature. Equation 36 allows an increase of shoot death rate after plants have undergone senescence. The parameter $P_{21,S}$ gives us needed control over late-season shoot death rates. We also assumed that plants can maintain only a given amount of leaf area before dieback occurs ($CRIT_{1,S}$). If the leaf area is greater than $CRIT_{1,S}$ and there is a biomass increase for the day, then the biomass equivalent to the amount of excess biomass also dies. Thus, dieback is defined as:

$$DS_5 = PHYTM_{1,S} - P_{16,S}\ CRIT_{1,S} \quad (37)$$

when $PHYTM_{1,S} > P_{16,S}\ CRIT_{1,S}$ after all other forms of death have been accounted for. Total shoot death (DS) is then:

$$DS = DS_1 + DS_2 + DS_3 + DS_4 + DS_5 \quad (38)$$

Grazing herbivores are allowed to trample as well as eat green vegetation. In the model, animals trample all or any part of the standing green vegetation on a site at the rate:

$$SC = PHYTM_{1,S}\ HYP(P_{14,S},\ SR) \quad (39)$$

where SR is the total stocking rate of domestic animals.

Daily wind run and precipitation remove standing dead from the site. We assume that no more than 25 percent of the standing dead can be knocked down on any given day. Thus, the transfer of standing dead to litter WPKD is calculated as:

$$WPKD = 0.25\ PHYTM_{4,S}\ [HYP(P_{10,S},\ WIND) + HYP(P_{11,S},\ PREC)] \quad (40)$$

where WIND is the daily wind run and PREC is the total daily precipitation. An animal herd can also knock down standing dead. Thus:

$$AKD = P_{12,S}\ PHYTM_{4,S}\ HYP(P_{13,S},\ SR) \quad (41)$$

Total transfer of standing dead to litter is:

$$TDSL = WPKD + AKD \quad (42)$$

Roots. Root respiration is calculated as:

$$ROOTR = P_{24,S}\ PHYTM_{2,S}\ ETR \quad (43)$$

where ETR is the effect of soil temperature on root respiration. Root mortality is calculated by the function:

$$ROOTM = P_{25,S}\ PHYTM_{2,S}\ EMR\ (1 - ETR) \quad (44)$$

where EMR (the effect of soil moisture on root respiration) is calculated using the 15-cm water potential and is:

$$EMR = ATANF(-W15,\ 20.0,\ 0.5,\ 1.0,\ 0.15) \quad (45)$$

Propagules. Seed mortality rate is:

$$SEEDM = P_{23,S}\ PHYTM_{3,S} \quad (46)$$

Seed respiration is not considered in the model.

Decomposition

Litter accumulates when dead shoots either fall naturally or are trampled and when domestic animals defecate. Dead roots and soil organic matter accumulate as live roots decay and as litter and dead roots decay, respectively. All species lose their identity during decomposition, and the subsequent processes are treated as site- rather than species-dependent. The decomposition processes proceed at rates limited by soil temperature and soil-water potential.

Temperature. The effect of temperature on decomposition is described as:

$$ETD = e^{-(6.8208 - 0.56535\ TS + 0.0116874\ TS^2)} \quad (47)$$

where TS is the soil temperature ($0 < TS < 38$). The same function is used in the ELM model (Innis 1978) where it was fit directly to data by Drobnick (1962). We modified the ELM decomposition function because simulated rates were too low; this descrepancy is probably due to the ELM model's use of average daily air temperature rather than soil temperature to control decomposition (fig. 6.5).

Soil-water potential. The effect of soil-water potential on decomposition is calculated as a site-dependent threshold response of the form:

$$EMD = THRESH(PNS_5,\ PNS_6,\ -W15) \quad (48)$$

where W15 is the 15-cm soil-water potential.

Decomposition rates. Decomposition rates are subsequently calculated as the maximum rate reduced by temperature and moisture. So, by defining:

$$VAR1 = ETD\ EMD \quad (49)$$

then:

$$TDRO = PNS_1 \; DROOTS_j \; VAR1 \tag{50}$$

$$TLO = PNS_2 \; ALIT_j \; VAR1 \tag{51}$$

$$TOA = PNS_3 \; AORG_j \; VAR1 \tag{52}$$

where the parameters in vector PNS are the maximum proportions of material to decompose, and TDRO, TLO, and TOA are the transfers of dead roots to soil organic, litter to soil organic, and soil organic to the atmosphere, respectively, for site j. For decomposition to occur, soil inorganic nitrogen must be available. In the transfers of dead roots and litter to soil organic, only 40 percent of the mass is retained (fig. 6.1); the rest is lost to the atmosphere presumably through soil respiration.

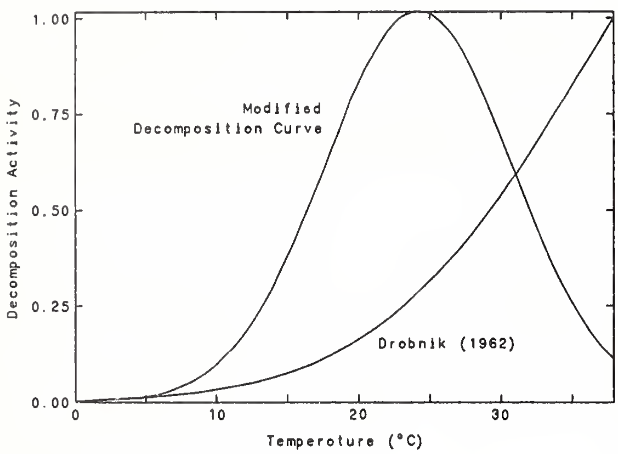

Fig. 6.5
The effect of temperature on organic matter decomposition rates.

Nitrogen Flows

Nitrogen Uptake

Nitrogen uptake by the roots occurs when there is soil inorganic nitrogen available for plant use. We assume that the only time plants attempt to take up nitrogen is while the plant is transpiring and that plant net carbon assimilation rate is an indicator of transpiration. Thus, nitrogen uptake occurs only if PN > 0. The expected uptake rate, for plants when this condition is met, is defined as:

$$TNUP_0(S) = \frac{CARB \; P_{28,S} \; SNIO_j}{P_{29,S} + SNIO_j} \tag{53}$$

where $TNUP_0(S)$ is the nitrogen demand for species S and CARB is the conversion of root phytomass to carbon. This algorithm is used since nitrogen uptake is based on the amount of carbon in the roots and $PHYTM_{2,S}$ is in biomass equivalents. The variable $SNIO_J$ is the soil inorganic-nitrogen concentration for site j in the upper 15 cm of the soil profile.

The variable $TNUP_0(S)$ is the maximum rate of nitrogen uptake. This amount is subsequently reduced by the effects of soil temperature (ETNU) and soil moisture (EMNU) which are calculated as:

$$ETNU = BELL(S,TS) \tag{54}$$

$$EMNU = 1 + 0.01 \; W15 \tag{55}$$

The effect of soil moisture on nitrogen uptake, EMNU, was developed purely from theory and the parameters were ascertained from model behavior. Nitrogen uptake is subsequently described as:

$$TNUP_1(S) = TNUP_0(S) \; ETNU \; EMNU \tag{56}$$

The model is constrained such that if the percentage of nitrogen of the roots ever reaches or surpasses 1 percent, then $TNUP_1(S) = 0$. Once $TNUP_1(S)$ has been calculated for all species, the nitrogen requirements for all species must be less than or equal to the amount of nitrogen available. Thus, let:

$$SNUP = \sum_{S=1}^{N} TNUP_1(S) \tag{57}$$

and $SNIO_j$ be the amount of available nitrogen on site j. If $SNUP < SNIO_j$, then no correction is needed. However, if $SNUP > SNIO_j$, then the available nitrogen must be partitioned between the species according to each species' demand. Thus, for each species S:

$$TNUP(S) = SNIO_j \frac{TNUP_1(S)}{SNUP} \tag{58}$$

which assumes the only priority for nitrogen is that large plants have more nitrogen available to them because of a larger rooting system. Competition for nitrogen is, however, accomplished through the maximum-nitrogen-uptake coefficient $(P_{28,S})$ and nitrogen-use efficiency coefficient $(P_{29,S})$.

Nitrogen Root/Shoot Balance

An empirical approach similar to that used in ELM is used to maintain the balance of nitrogen between roots and shoots. We assume that plants maintain a ratio between the concentration of nitrogen in the shoots and roots (SY) and that the ratio is predictable throughout the growing season as a function of Julian day DAY (fig. 6.6). By identifying the days when senescence begins $(CRIT_{7,S})$ and ends $(CRIT_{8,S})$, SY can be calculated by the relationship:

$$SY = \begin{cases} 3.0 & DAY < CRIT_{7,S} \\ 1.0 & DAY > CRIT_{8,S} \\ 1.0 + 2.0 \dfrac{CRIT_{8,S} - DAY}{CRIT_{8,S} - CRIT_{7,S}} & \text{otherwise} \end{cases} \tag{59}$$

Also, if new growth occurs following $CRIT_{8,S}$ then the new SY for the growth will be three. We also assume that the ratio of percent root to percent shoot nitrogen varies little from day to day. Therefore, the total nitrogen in the roots and shoots is partitioned daily by the function:

$$SY = \frac{\dfrac{PNC_{1,S} + NUS}{PHYTM_{1,S}}}{\dfrac{PNC_{2,S} - NUS}{PHYTM_{2,S}}} \qquad (60)$$

so that:

$$NUS = \frac{SY\ PNC_{2,S}\ PHYTM_{1,S} - PNC_{1,S}\ PHYTM_{2,S}}{PHYTM_{2,S} + PHYTM_{1,S}\ SY} \qquad (61)$$

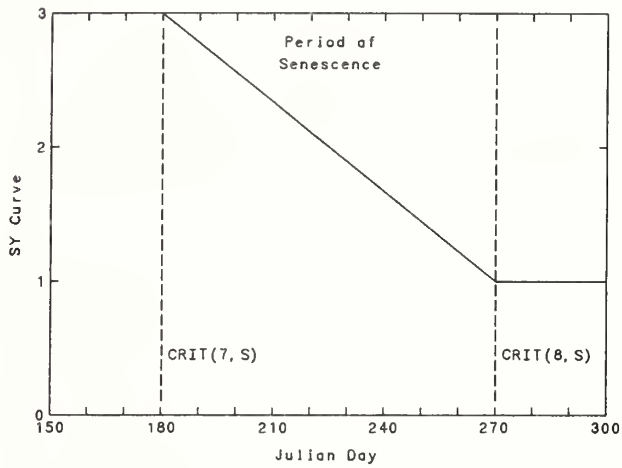

Figure 6.6
Ratio of green shoot to live root nitrogen concentrations versus time of the year.

where NUS is the transfer rate of nitrogen from the roots to the shoot. Note that if nitrogen accumulates in the shoots, NUS < 0.0, thereby translocating nitrogen back into the roots. To ensure that nitrogen does not move too rapidly between roots and shoots, we allow translocation of no more than 50 percent of the root or shoot nitrogen during any single day.

Other Plant Nitrogen Dynamics

We assume, in a manner similar to McGill et al. (1981), that nitrogen flows between various components of the model based upon the amount of biomass being translocated during a given time step. For root mortality and trampled shoots, the carbon:nitrogen ratio for the material being transported is the same as the parent material. Thus:

$$MRM = ROOTM \frac{PNC_{2,S}}{PHYTM_{2,S}} \qquad (62)$$

$$RNSC = SC \frac{PNC_{1,S}}{PHYTM_{1,S}} \qquad (63)$$

where MRN and RNSC are the nitrogen in dying shoots and in trampled live shoots, respectively. Shoot nitrogen appears to be conserved as the plant dies (Clark 1977); thus, the C:N ratio of dying plants will be higher than in live shoots. We assume that dying plants have a C:N ratio that is 10.0 higher than that of live shoots. Therefore:

$$RNDS = \frac{DS}{\dfrac{PHYTM_{1,S}}{PNC_{1,S}} + 10} \qquad (64)$$

where RNDS is the nitrogen transferred to standing dead.

The same type of dynamics as used for most of the other nitrogen flows is used to transfer standing dead to litter. The exception is that leaching removes some of the nitrogen from the standing dead plant material. This is accomplished in a simplistic fashion by using the expression:

$$TNDL = 1.01\ TDSL \frac{PNC_{4,S}}{PHYTM_{4,S}} \qquad (65)$$

where TNDL is translocated standing-dead-shoot nitrogen. By using this formulation, 1 percent more nitrogen is removed from the standing-dead compartment than would normally be expected if the transfer was based solely on the C:N ratios.

Reproductive portions of the phytomass pool are assumed to contain 4 percent nitrogen. Therefore, when seeds die or germinate they release an equivalent amount of nitrogen to the litter or shoot and root compartments, respectively. Nitrogen from the seeds (SMN), therefore, enters the litter at the rate:

$$SMN = 0.04\ SEEDM \qquad (66)$$

Nitrogen from germinating seeds is partitioned between the roots and shoots depending on the optimum root:shoot ratio ($P_{9,S}$). Thus, if:

$$GBN = 0.04\ GERM \qquad (67)$$

where GBN is the amount of nitrogen in the germinating biomass, then:

$$P_{9,S} = \frac{RGBN}{GBN - RGBN}$$

so that:

$$RGBN = GBN \frac{P_{9,S}}{1 + P_{9,S}} \qquad (68)$$

$$SGBN = GBN - RGBN \qquad (69)$$

where RGBN and SGBN are the amounts of nitrogen designated for roots and shoots, respectively.

Finally, nitrogen is translocated to the propagules during seed formation according to the amount of nitrogen needed to bring the propagule compartment up to 4 percent. This is accomplished by selecting

$$\text{PROPN} = \max \begin{bmatrix} 0.04\,(\text{PHYTM}_{3,S} + \text{TSP}) - \text{PNC}_{3,S} \\ 0 \end{bmatrix} \quad (70)$$

where PROPN is the nitrogen translocated from shoots to propagules.

Belowground Dynamics

Decomposition at and below the soil surface removes organic material and subsequently recycles nitrogen for use by plants. In the model, dead roots and litter are decomposed into soil organic matter while the soil organic matter is reduced to carbon dioxide and inorganic nitrogen. Nitrogen is removed from dead roots and litter according to the nitrogen concentration of each respective donor pool at the rates:

$$\text{TNDRO} = \text{TDRO}\,\frac{\text{DROOTN}_j}{\text{DROOTS}_j} \quad (71)$$

$$\text{TNLO} = \text{TLO}\,\frac{\text{ALITN}_j}{\text{ALIT}_j} \quad (72)$$

where TNDRO and TNLO are the level of nitrogen removed from dead roots and litter from site j, respectively. We assume that soil organic matter is maintained at a C:N ratio of 10 (4 percent nitrogen). So, the amount of inorganic nitrogen immobilized by litter and dead-root decomposition can be defined as the difference between the nitrogen needed to maintain an organic matter C:N ratio of 10.0 and the nitrogen released by decomposition. Thus, since only 40 percent of the carbon is retained during decomposition, the amount of nitrogen passed from dead roots and litter to soil organic matter is:

$$\text{RNDR} = 0.4\ \text{TDRO}\ 0.04 \quad (73)$$

$$\text{RNL} = 0.4\ \text{TLO}\ 0.04 \quad (74)$$

where RNDR and RNL are the amounts of nitrogen transferred from dead roots and litter to soil organic matter, respectively, and are required to maintain the proper C:N ratios. Subsequently, nitrogen is mineralized at rates of:

$$\text{IL} = \text{RNL} - \text{TNLO} \quad (75)$$

$$\text{IR} = \text{RNDR} - \text{TNDRO} \quad (76)$$

where IL and IR are the amounts of nitrogen immobilized from the decomposition of litter and dead roots, respectively.

Nitrogen is also mineralized during decomposition of soil organic matter according to the relationship:

$$\text{MN} = 0.04\ \text{TOA} \quad (77)$$

where MN is the amount of mineralized N, and TOA is the amount of soil organic matter undergoing decomposition.

Other processes affecting the amount of soil inorganic nitrogen are limited to nitrogen fixation (FN) and denitrification. Nitrogen fixation is assumed to be purely a response to precipitation rate, and thus, symbiotic fixation has not been considered. For eastern Colorado shortgrass prairie, Reuss and Copley (1971) estimated an annual input of about 0.3 g m^{-2} nitrogen as a result of precipitation while only about 0.1 g m^{-2} was fixed by free-living organisms (Copley and Reuss 1972). Thus, a maximum seasonal input of about 0.5 g N m^{-2} can be expected on the shortgrass prairie. Since the annual rate of precipitation is about 50 cm, and by assuming nitrogen enters the soil system in proportion to the daily precipitation rate (PREC), the quantity of nitrogen fixed is:

$$\text{FN} = 0.01\ \text{PREC} \quad (78)$$

Inorganic nitrogen is lost from the soil through denitrification. This process is primarily controlled by the soil-water potential of the top 15 cm. Thus:

$$\text{EMDN} = 1 - \text{HYP}(\text{PNS}_4, -\text{W15}) \quad (79)$$

where EMDN is the effect of water potential on denitrification.

Subsequently, denitrification (DEN) is calculated as a logistic equation

$$\text{DEN} = \frac{0.008\ \text{EMDN}}{1 + 6.73\, e^{-0.067\,\text{NPPM}}} \quad (80)$$

where NPPM is the soil nitrogen concentration in parts per million (fig. 6.7).

STATE VARIABLE ACCOUNTING

State variables are updated on a daily basis. Phytomass compartments are calculated by the set of equations:

$$\text{PHYTM}_{1,S} = \text{PHYTM}_{1,S})_0 + \text{PN} + \text{SHOOTG} + \text{TRS} - (\text{SC} + \text{DS} + \text{TSP} + \text{TSR} + \text{RESP}) \quad (81)$$

$$\text{PHYTM}_{2,S} = \text{PHYTM}_{2,S})_0 + \text{ROOTG} + \text{TSR} - (\text{ROOTR} + \text{ROOTM} + \text{TRS}) \quad (82)$$

$$\text{PHYTM}_{3,S} = \text{PHYTM}_{3,S})_0 + \text{TSP} - (\text{GERM} + \text{SEEDM}) \quad (83)$$

$$PHYTM_{4,S} = PHYTM_{4,S)_0} + DS - TDSL \quad (84)$$

$$DROOTS_k = DROOTS_{k)_0} + TOTDR - TDRO \quad (85)$$

$$ALIT_k = ALIT_{k)_0} + TOTLT - TLO \quad (86)$$

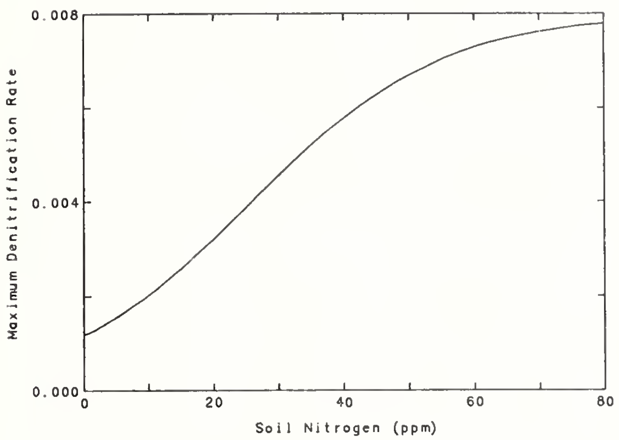

Figure 6.7
Maximum rate of soil denitrification as a function of inorganic soil nitrogen.

$$AORG_k = AORG_{k)_0} + 0.4\,(TDRO + TLO) - TOA \quad (87)$$

where:

$$TOTDR = \sum_{S=1}^{nspec} ROOTM_S \quad (88)$$

and:

$$TOTLT = \sum_{S=1}^{nspec} (SC_S + TDSL_S + SEEDM_S) \quad (89)$$

Nitrogen state variables are incremented in a similar manner using the equations:

$$PNC_{1,S} = PNC_{1,S)_0} + NUS + SGBN - (RNSC + RNDS + PROPN) \quad (90)$$

$$PNC_{2,S} = PNC_{2,S)_0} + RGBN - (MRN + NUS) \quad (91)$$

$$PNC_{3,S} = PNC_{3,S)_0} + PROPN - (GBN + SMN) \quad (92)$$

$$PNC_{4,S} = PNC_{4,S)_0} + RNDS - TNDL \quad (93)$$

$$DROOTN_k = DROOTN_{k)_0} + TOTDRN - TNDRO \quad (94)$$

$$ALITN_k = ALITN_{k)_0} + TOTLTN - TNLO \quad (95)$$

$$AORGN_k = AORGN_{k)_0} + RNL + RNDR - MN \quad (96)$$

$$SNIO_k = SNIO_{k)_0} + FN + MN - (MD + IL + IR + SNUP) \quad (97)$$

where:

$$TOTDRN = \sum_{S=1}^{nspec} MRN_S \quad (98)$$

and:

$$TOTLTN = \sum_{S=1}^{nspec} (TNDL_S + RNSC_S + SMN_S) \quad (99)$$

PARAMETERIZATION

The rangeland plant growth model uses 42 parameters to simulate carbon and nitrogen dynamics (table 6.1). The primary plant parameters ($P_{I,S}$) are used to physiologically control the responses of the various processes to abiotic variables. Many of the processes do not turn on until some critical value of a control variable is attained. The critical values for these on/off processes are contained in $CRIT_{I,S}$. The vector PNS_J contains the site specific parameters that control decomposition and denitrification rates.

To our knowledge, a data set that could supply all the parameters for the plant model does not exist. Therefore, an empirical approach must be taken to derive them. Some parameters can be determined from small data sets and input directly into the model. We recommend that parameters estimated using this procedure be considered constant and only adjusted slightly in subsequent simulation runs. Other parameters seem not to be supported by ecophysiological data. These parameters must be estimated and then adjusted by comparing simulated output with actual field data.

Initial values for the phytomass state variables and soil inorganic nitrogen must be obtained from existing data for the sites to be simulated. Estimates for the phytomass and soil state variables are given in tables 6.3 and 6.4, respectively. Presently, the initial nitrogen state variables are determined from the biomass inputs (table 6.5). For additional sites, initial conditions must be estimated. Data for live and dead shoot biomass should be available. Propagule biomass is probably quite low for perennial species, at least for shortgrass prairie; since sexual reproduction is of minor importance on rangeland, the model can be run using no initial propagule biomass. For annual plants, the initial seed biomass will need to be adjusted to obtain the desired results. Perhaps the best way to determine peak live root biomass, in the absence of such data, is to multiply the peak standing crop for a species by its maximum root:shoot ratio ($P_{9,S}$). If data are not available for dead roots, assume that the total

root biomass is 70 percent dead and 30 percent live. Then, the initial dead root biomass is defined as:

$$DROOTS_j = \frac{0.7}{0.3} \sum_{S=1}^{nspec} PHYTM_{2,S} \qquad (100)$$

Litter biomass should be available for each site. Soil organic matter is quite large and should remain approximately constant for the duration of the simulation. Soil inorganic nitrogen is very low in rangeland soils, and during the active growing season it may be trivial.

Table 6.3
Nonspecies-specific site parameters and initial conditions for the rangeland plant growth model simulating vegetation dynamics of a single PAWNEE range site

Symbolic name	Value	Symbolic name	Value
PNS_1	0.1	SNIO(J)	0.1
PNS_2	.15	DROOTS(J)	610.0
PNS_3	.004	LITTER(J)	147.0
PNS_4	.028	AORG(J)	2000.0
PNS_5	8.0		
PNS_6	1.2		

SIMULATION RESULTS

Two simulation runs were conducted to demonstrate the types of questions the SPUR plant growth model can be used to address. The model will undoubtedly be used to generate time series traces of various components of the plant system. These series many include such variables as standing green graminoid production (fig. 6.8), forb and shrub live-root production (fig. 6.9), or yearly summary statistics by species group (table 6.6).

For the second simulation, suppose the effect of a changing climate on the production of rangeland is of interest. Specifically, the effects of temperature and radiation reductions on aboveground and belowground net primary production, and aboveground peak standing crop, are to be investigated. An experiment to test the effect of these climatic changes was conducted using the SPUR model. A factorial experiment was designed using a standard set of parameters for the Central Plains Experimental Range (CPER) in northeastern Colorado (the PAWNEE site). The model was run using warm-season grasses (WSG), cool-season grasses (CSG), warm-season forbs (WSF), cool-season forbs (CSF) and shrubs (SHR). Treatments were combinations of 0, 3, 6 and 9 °C decreases in temperature, and 0, 25, 50, and 75 percent decreases in solar radiation (table 6.7). Means were statistically compared using Tukey's hst. These types of reductions tended to favor C_3 over C_4 plants, and forbs over grasses. Also, reductions in light were more tolerable for all plant groups than reductions in temperature. Under the most severe treatment, a 9 °C reduction in temperature and a 75 percent reduction in light, shrubs were affected the least.

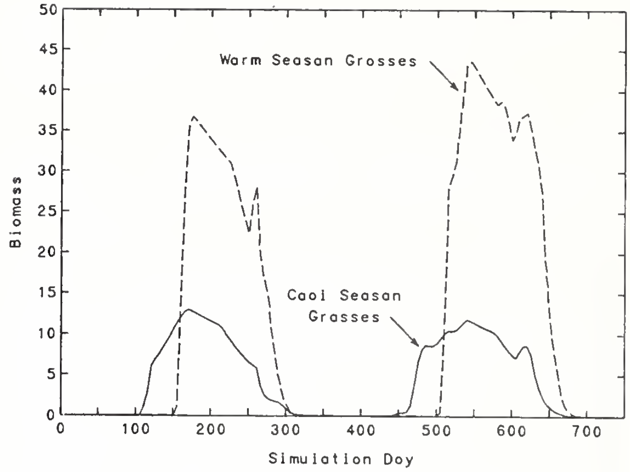

Figure 6.8
Sample output from a 2-year simulation showing the time series for warm- and cool-season aboveground green biomass.

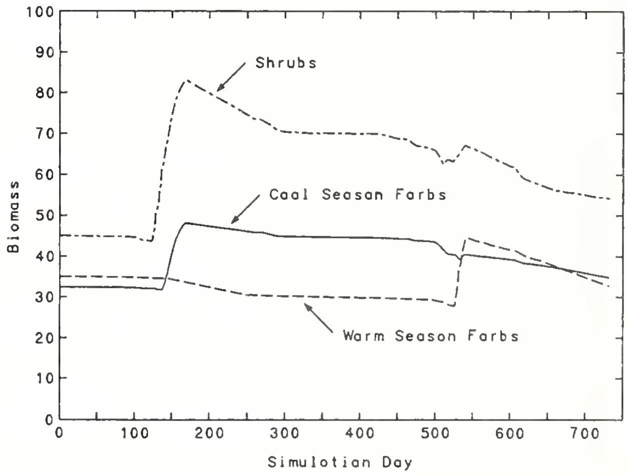

Figure 6.9
Sample output from a 2-year simulation showing the time series for warm- and cool-season forbs and shrub root biomass.

SUMMARY

A primary producer model has been developed which simulates aboveground and belowground plant dynamics. The model is unique among plant growth models in that it is capable of simulating multiple species on multiple sites, and it includes a method of allowing plants to compete for available nitrogen and water. Though the model was originally developed for rangelands, it can also accommodate the simulation of monocultures. The plant model uses some techniques of previous primary producer models but is unique in

Table 6.4
Species-specific parameter set and initial conditions for the rangeland plant growth model used in SPUR to simulate vegetation dynamics of a single PAWNEE range site

Symbolic name	Species group				
	Warm-season grass	Cool-season grass	Warm-season forb	Cool-Season forb	Shrub
$P_{1,S}$	75.0	25.0	20.0	12.0	15.0
2	.4	2.0	.15	1.3	1.3
3	45.0	37.0	45.0	35.0	40.0
4	27.0	20.0	27.0	20.0	21.0
5	5.0	3.0	5.0	3.0	3.0
6	25.0	10.0	15.0	7.0	8.5
7	9.96	6.29	7.04	4.75	6.4
8	.7	.7	.7	.7	.7
9	10.0	10.0	4.0	4.0	5.0
10	-.0001	-.0002	-.0004	-.0005	-.00002
11	-.25	-.4	-.6	-.65	-.00025
12	.05	.05	.06	.06	.0007
13	-.009	-.01	-.01	-.01	-.0009
14	-.005	-.006	-.006	-.006	.0
15	.004	.004	.004	.005	.0005
16	.015	.02	.03	.03	.03
17	.01	.02	.05	.05	.04
18	.005	.005	.005	.005	.005
19	.005	.01	.005	.005	.01
20	22.0	72.0	30.0	15.0	19.0
21	.06	.06	.05	.05	.05
22	.0	.0	.0	.0	.0
23	.01	.01	.01	.01	.01
24	.0025	.0025	.001	.0005	.0015
25	.005	.004	.002	.001	.0005
26	.008	.009	.010	.011	.01
27	-130.0	-115.0	-120.0	-110.0	-130.0
28	.003	.003	.002	.002	.001
29	.42	.42	.21	.21	.3
$CRIT_{1,S}$	3.0	3.0	3.0	3.0	3.0
2	-2.0	-6.0	-1.0	-3.0	-4.0
3	12.5	8.5	13.0	9.0	8.5
4	-12.0	-10.0	-12.0	-8.0	-8.0
5	-5.0	-3.0	-5.0	-3.0	-1.0
6	180.0	150.0	200.0	150.0	160.0
7	190.0	165.0	200.0	150.0	200.0
8	220.0	195.0	220.0	180.0	220.0
$PHYTM_{1,S}$	.0	.0	.0	.0	.0
2	256.4	62.7	35.0	32.4	45.0
3	.0	.0	.0	.0	.0
4	54.0	11.0	3.0	6.0	30.0

Table 6.5
Percentage nitrogen content for the initial state variables of the rangeland plant growth model

State variable	Percentage nitrogen
Green shoots	3.0
Live roots	1.0
Propagules	4.0
Standing dead shoots	.5
Dead roots	.6
Litter	1.0
Soil organic matter	4.0

Table 6.6
Simulated peak standing crop, peak C:N ratio and season-long integrated carbon assimilation rate for PAWNEE site

Species group	Peak standing crop	Peak C/N	Integrated carbon assimilation
	Year 1		
WSG	37.8	12.99	78.80
CSG	12.6	13.16	37.20
WSF	3.8	13.20	1.62
CSF	10.3	13.33	9.76
SHR	16.1	13.25	23.32
	Year 2		
WSG	46.0	19.32	106.40
CSG	11.9	13.47	29.28
WSF	10.9	13.61	16.40
CSF	9.6	13.25	4.32
SHR	13.0	26.67	6.88

Table 6.7
Results from a sample simulation of a shortgrass prairie showing the effects of temperature and radiation reductions on the vegetation dynamics[1/]

Factor	Yearly net primary production[2/]		
	Belowground	Aboveground	Peak standing crop
	Plant functional group		
WSG	0.47 c	0.50 c	0.57 d
CSG	.63 b	.66 c	.67 c
WSF	.65 b	.63 b	.78 b
CSF	.78 a	.78 a	.87 a
SHR	.81 a	.82 a	.87 a
	Temperature Reduction (°C)		
0	.87 a	.87 a	.86 a
3	.77 b	.77 b	.79 b
6	.59 c	.61 c	.65 c
9	.45 d	.47 d	.53 d
	Light Reduction (%)		
0	.77 a	.79 a	.82 a
25	.71 b	.72 b	.76 b
50	.64 c	.65 c	.67 c
75	.55 d	.56 d	.57 d

[1/]Values represent means for the ratio between treatment and non-treatment simulated phytomass.

[2/]Means within columns of each factor followed by the same letter do not differ significantly at the 0.05 level. Interaction means were not tested.

its overall complexity and small size. Net carbon dioxide assimilation is the process by which carbon dioxide enters a plant. Subsequently, the carbon and nitrogen content of standing green, live roots, propagules, standing dead, litter, dead roots, and soil organic matter are simulated. Soil inorganic nitrogen is also included in the model. The model produces generally good phytomass and nitrogen simulations and produces results which are typical of shortgrass prairie phytomass dynamics in northeastern Colorado.

The model can simulate up to seven plant species or species groups on a total of nine range sites. It incorporates processes which are common to C_3 and C_4 plants but does not consider plants with Crassulacean Acid Metabolism. When coupled with the other components of the SPUR model, the plant component allows testing of grazing regimes, precipitation variation, and fertilizer application. The model has been successfully used to simulate a two-species system and shows promise when expanded to entire plant communities. For research and management applications, the model can produce output which will aid in gleaning information at costs significantly lower than direct experimentation. The primary production model should be able to aid managers in making decisions, such as the effect of grazing on range forage production and range condition.

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7. ANIMAL COMPONENT

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INTRODUCTION

Rational multiple-use planning appropriate to individual range allotments should consider the harvesting of forage produced. Livestock may be an integral component of the forage-harvesting system, and they provide a major economic output from rangelands (Forest-Range Task Force 1972). Likewise, nonlivestock species harvest significant quantities of forage (Wagner 1978), and their relative abundance may affect the aesthetic value of the rangeland to the general public (Allen 1978). Therefore, the ultimate utility to the general public of a rangeland managed in a particular way is a complex and poorly defined function. Mathematical modeling techniques provide useful methods to experiment with hypothetical range-resource-management scenarios.

The objective of the animal-component modeling group was to develop an integrated component model that would simulate herbage removal by cattle and other herbivores from shortgrass prairie rangelands at moderate stocking rates and predict stocker steer weight (kg) over a normal growing season within a coefficient of variation. An attempt was made to amalgamate existing component models wherever possible and develop new information only as necessary to interface the existing models. For the sake of simplicity, existing models were abstracted when possible in keeping with the component objective.

ASSUMPTIONS

Explicit in the model objective statement is the limitation that the model, as formulated, applies to only moderate stocking-rate situations. It is assumed that the relative abundance of forage functional groups such as warm-season grasses, cool-season grasses, forbs, and shrubs will have little effect on diet composition at moderate stocking rates. The mathematics used to simulate diet selection also imply that similar biological systems of actual diet selection are used by all herbivores. Unless the forage supply in a particular location or the biomass of a particular functional group has been exhausted, grazing pressure on that location or functional group is constant throughout the grazing season. Both location and forage preference have been assumed to be static with respect to environmental conditions.

To make livestock grazing management decisions, it is assumed that the nonlivestock species will be adequately accounted for with a sink for the forage they harvest. Within a single time step, consumption by herbivores other than cattle precedes consumption by steers. Thus, competition among herbivore species exists only across time.

The sequence of consumer demands on the herbage supply is based upon the assumed competitive advantage and relatively greater mobility of other composited herbivores versus domestic cattle. Rather than attempt to simulate the myriad of possible livestock combinations, it is assumed that yearling steers can be used as productivity indicators. Patterns of forage harvest more typical of other livestock species or other classes of cattle may be achieved with appropriate parameter estimates for the preference vectors which govern grazing behavior in the model.

In the simulation of intake by steers, grazing time does not constrain forage harvest. Steers are assumed to eat until either their energy demand has been satiated or their physical capacity has been reached. Simulated growth of steers has been based on the assumption that mature size and maturing rate define the genetic potential for growth. The simulated growth of steers deviates from the potential growth only due to nutritional environment, either past or present. The priority structure implicit in the model results sequentially in weight being maintained, growth made in accordance with genetic potential, and excess available energy deposited as fat.

HERBIVORE-COMPONENT DESCRIPTION

The structure, sequence, and flow of the animal component is illustrated in figure 7.1. Herbivores exert their dietary demand on the plant supply. Within a single time step, consumption by herbivores other than cattle preceeds consumption by steers. Cattle response is monitored as weight change.

The rangeland ecosystem to be simulated must be divided into nine or fewer distinct sites with seven or fewer distinct cross-classified functional groups or plant species. Two classes of forage exist for each functional group or plant species, live and dead. The species groups are defined by the user to characterize the vegetation and anticipated animal grazing response of the rangeland to be simulated.

Stocker Cattle Model

The basic structure of the stocker cattle model has been adapted from the Texas A&M University (TAMU) Beef Simulation Model (Sanders 1974, 1977; Sanders and Cartwright 1979). Further modifications also used herein were incorporated into TAMU Beef Simulation Model by Notter (1977).

The philosophy of these authors defines how uncertainty of theoretically appropriate functional forms and the covariance structure among parameter estimates should be handled in a deterministic model. It leads them to tune the entire model to data and embed the resultant parameter estimates within the computer code. Thus, this portion of the animal component is viewed as an empirical or predictive model.

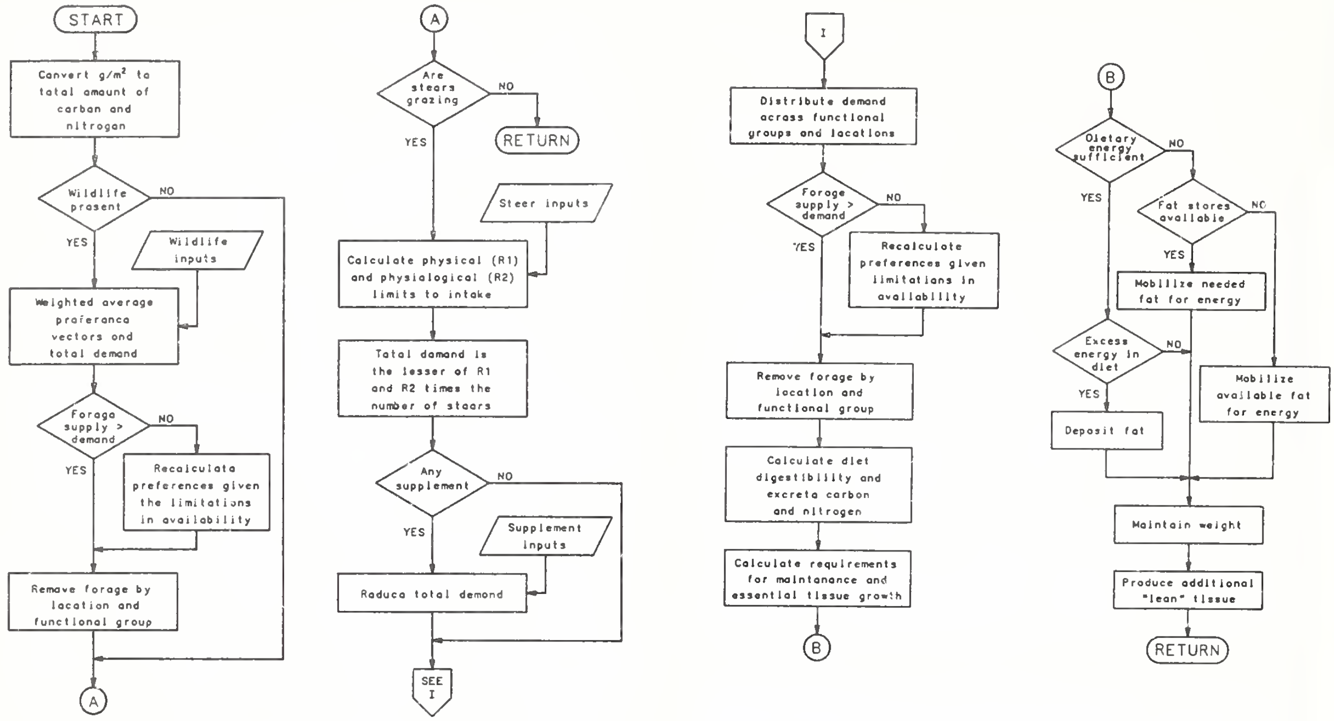

Figure 7.1
Conceptual flow diagram for the herbivore component of the SPUR model.

The grazing season is defined by Julian dates of turnout to pasture and removal from pasture. The initial physical and physiological status of the steers is inferred from their age and weight at turnout.

Supplemental feed can be offered between input Julian dates. Steers consume all supplemental feed before eating any of the available herbage. Thus, the available herbage provides a pool to makeup any difference between the animal demand and the feed offered by the manager.

Animal demand is the lesser of consumption limited by a physical capacity or energy satiation. If DIG is the digestible fraction of the forage, then the initially simulated physical constraint (R2) is a multiplicative function of the steer's potential size (WM) and the reciprocal of the indigestible fraction of the forage. The relationship is:

$$R2_0 = 0.0107 \frac{WM}{1 - DIG} \qquad (1)$$

Steers less than 240 days old or with potential size less than 44 percent of asymptotic or mature weight (WMA) are thought to have reduced capacity relative to their size than more mature counterparts (Sanders 1977). Additionally, diets which contain less than 6 percent crude protein (CP) are thought to be processed more slowly than diets higher in crude protein (Sanders 1977). Therefore, empirical functions of degree of maturity (DM) and CP reduce R2 under these respective conditions, or:

$$R2_1 = \begin{cases} R2_0, \text{ if} \\ \quad \text{age} \geq 240 \text{ days or WM} \geq 0.44 \text{ WMA} \\ R2_0\,(6.0\text{ DM} - 6.8\text{ DM}^2 - 0.314), \text{ if} \\ \quad \text{age} < 240 \text{ days or WM} < 0.44 \text{ WMA} \end{cases} \qquad (2)$$

and:

$$R2 = \begin{cases} R2_1 & CP \geq 0.06 \\ R2_1 \left[\dfrac{CP}{0.06}\right]^{0.6} & CP < 0.06 \end{cases} \qquad (3)$$

The physical constraint applies to most all forage diets except those composed almost entirely of very immature green biomass that is relatively high in nitrogen. The physiological limit (R1) on dry matter intake is simulated as:

$$R1 = 0.1 \frac{WM^{0.75}}{DIG} \qquad (4)$$

In this expression, $WM^{0.75}$ is the metabolic body size (Brody 1945) of the average steer. The physiological limit would be expected to apply when grazing immature green biomass that is relatively high in nitrogen. The relationship of WM and DIG in determination of which limitation applies and the boundary conditions is presented in figure 7.2. Total dry-matter demand by steers

is calculated as the product of the minimum of R1 (equation 4) and R2 (equation 1) times the number of steers.

Digestibility is related to the nutritive value of a forage or a forage diet and affects both voluntary intake and the quantity of assimilated nutrients available for support of herbivores. Crampton et al. (1960) determined that voluntary intake or maximum potential intake by ruminants varies considerably among forages. Van Soest et al. (1978) reported that digestibility accounts for approximately 37 percent of the variation in intake; therefore, some differences in intake of forages with the same digestibility might be expected. Montgomery and Baumgardt (1965) and Conrad (1966) discussed a dual-phased relationship of digestibility and intake where, up to a point, digestibility and intake are positively related, and beyond that point increased diet digestibility results in reduced intake. The first phase might be viewed as a constraint imposed by the capacity of the animal, while the second phase would be related to energy satiation. It is likely that animals grazing rangelands would not achieve energy satiation.

Many of the precepts on how organisms grow were developed by Brody (1945). Sanders (1974, 1977) and Notter (1977) integrated the relationships of weight with height and weight with chronological age to describe condition-constant growth in weight. The observed weight of an animal might deviate from the predicted condition-constant weight due to either excessive or subminimal energy intake (ARC 1965, NRC 1976). Constant condition does not imply a constant ratio of fat to nonfat tissue in the body. Newborn calves in good condition have about 3 percent body fat

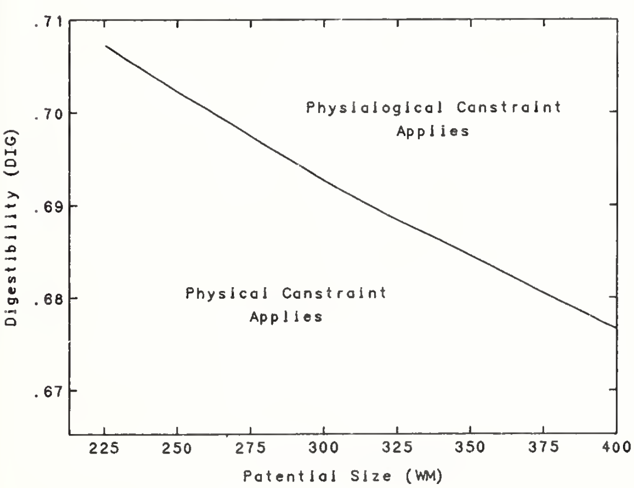

Figure 7.2
Relationships of digestibility, potential size, and constraints on intake.

(Maynard et al. 1965), while yearling steers are extremely thin with only 3 percent body fat (Trowbridge et al. 1918). If present, excess fat may be mobilized to provide energy for growth of nonfat tissues when energy intake is otherwise limiting.

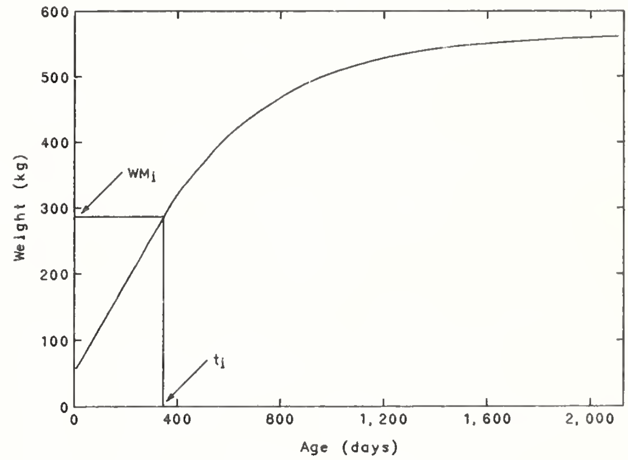

Figure 7.3
Growth curve for a crossbred steer in good condition with a WMA of 550 kg.

Simulated growth of steers is based on the assumption that potential mature size reflects a large percentage of the differences in the pattern of growth among cattle. Present and previous nutritional status of the simulated steers is also taken into account. A theoretical growth curve (fig. 7.3) for an average crossbred steer in "good condition" (3 percent body fat at birth and 25 percent body fat at maturity) is derived from WMA. Birth weight (BW) is estimated as 1/15 of WMA. From birth until the projected weight (WM) from the theoretical growth curve reaches approximately 60 percent of WMA, the theoretical change in weight per day is constant:

$$WM = BW + t\,\frac{(WM_i - BW)}{t_i} \qquad (5)$$

where t is the age of the steer measured in days from birth and the subscript i denotes theoretical weight (WM_i) or age (t_i) at the inflection point of the growth curve. The time of inflection is:

$$t_i = 369.5\left[\frac{WMA}{500}\right]^{0.3} \qquad (6)$$

where 369.5 is the age at the inflection point of the growth curve for a female with WMA equal to 500 kg.

After the linear phase of growth, the theoretical growth curve is a Gompertz type function:

$$WM = WMA\,(1 - B\,e^{-A2t}) \tag{7}$$

where:

$$B = 1 - \frac{BW}{WMA} \tag{8}$$

and:

$$A2 = \frac{0.00237}{\left[\frac{WMA}{500}\right]^{0.3}} \tag{9}$$

Maturing rate (A2) is empirically adjusted to conform to the theoretical growth curve of an individual with WMA equal to 500 kg. In equation 9, 0.00237 is the maturing rate estimated from data of an individual with mature weight at 25 percent body fat equal to 500 kg. Implicit in the parameters of equations 5-9 is 15 percent heterosis for growth rate. Parameters for the original TAMU beef simulation model are estimates primarily from data on females. Simulation of steers necessitates correction of WM for sex. Males have approximately 50 percent greater WMA than do females. Theoretical lean-tissue growth of simulated steers is reduced when their actual weight (W) is less than WM by the multiplicative adjustment:

$$X = 1 - [4\,(1 - \frac{W}{WM})]^{0.35} \tag{10}$$

The catabolism of lean tissue has not been considered in the model.

Energy Utilization

Digestibility of forages varies with plant species and with maturity of the plant (Waldo and Jorgenson 1981). The protein content of forage diets has been reported as having a significant positive relationship with digestibility (Bredon et al. 1963, Horton et al. 1980, Tinnimit and Thomas 1976, Cook et al. 1977, Brown et al. 1968, Rao et al. 1973) and presumably, therefore, with intake. Additionally, low levels of protein content reduce intake (Campling et al. 1962). Protein (calculated from nitrogen) in herbage is related to the maturity of the plant and to the proportions of structural carbohydrates that are known to be related to forage productive value (Van Soest 1967). Total digestible nutrients (TDN) are estimated from the crude protein (CP) content of the selected diet as:

$$TDN = \begin{cases} 0.371 + 2.4\,CP & CP < 0.17875 \\ 0.80 & CP \geq 0.17875 \end{cases} \tag{11}$$

In the model, CP is calculated as percent nitrogen multiplied by 6.25. Parameters were estimated by fitting a linear regression model to data from a sampling of the CP and TDN values for shortgrass prairie plant species given in the "Atlas of Nutritional Data on United States and Canadian Feeds" (NAS 1971).

The TDN required to maintain W is given as:

$$M = C2\,W^{0.75}\left[\frac{WM}{W}\right]^{0.5}\left[1.5\,\frac{WMA}{WM}\right]^{0.25} \tag{12}$$

where C2 is the TDN required to maintain one kilogram of metabolic weight calculated as:

$$C2 = \frac{0.0214}{0.243\,DIG + 0.486} \tag{13}$$

The terms $(WM/W)^{0.5}$ and $(Q2/WM)^{0.25}$ serve as corrections for condition and degree of physiological maturity, respectively. Growth (kg) of nonfat and fat tissues have marginal costs in TDN units of:

$$MCL = 0.82\,\frac{0.34}{0.333\,DIG + 0.148} \tag{14}$$

and:

$$MCF = 0.82\,\frac{2.58}{0.662\,DIG - 0.07} \tag{15}$$

respectively, with the coefficient 0.82 accepted as the conversion of digestible energy to metabolizable energy (ARC 1965).

The priority structure implicit in the model is such that weight is maintained, growth is made along the theoretical growth curve, and any excess available energy is deposited as fat. If the available TDN is not sufficient to meet the requirements for weight maintenance and the nonfat tissue fraction of growth, then fat is mobilized to supply additional energy. One unit of fat is assumed to be equivalent to 10/3 units of TDN. Change in weight is therefore simulated as gain in nonfat tissue plus the change in fat mass.

Grazing Behavior and the Demand for Herbage

For herbivores other than steers let:

k = the number of herbivorous species other than steers (limit 10);

d_w = estimated dry matter intake by a mature member of the w^{th} herbivorous species; and

n_w = the number of mature equivalents of the w^{th} herbivores species.

For each simulated herbivorous species, the option exists to specify a calendar date when the species enters and leaves the system within a year. When the species is not present, the number of mature equivalents is set to zero.

Total dry-matter demand by herbivores other than steers (DW) is:

$$DW = \sum_{w=1}^{k} d_w n_w \qquad (16)$$

When animals are provided a variety of potential food sources, they influence patterns of energy flow, nutrient cycles, and the structure of plant communities through the effects of selective grazing. Diet selection is viewed by theoretical ecologists as a major element of the adaptive strategies of herbivore species. Divergence of diet selection patterns is an important determinant of the species composition of a community and has been correlated with consumer size, food availability, dietary strategy and competition (reviewed by Schoener, 1971). Dietary selection tactics were summarized by Ellis et al. (1976) to include factors of food density, relative abundance of preferred and less preferred foods, consumer nutrient requirements as affected by physiological state and environment, size of consumer, previous experience, palatability, and satiety. Preference was described as the desire of a consumer for a particular class of food relative to other foods when all were equally available. When foods are present, equally available, and abundant, then preference should determine food selection.

There is little data which identifies the basic factors determining preference by herbivores. Relationships of forage structure to diet composition are not necessarily causal and could alternatively be the effect of selection. There are numerous research reports giving values for dietary botanical composition of herbivores; however, many do not report concurrent herbage availability. Van Dyne et al. (1980) presented a summary of much of the literature on diet selection and were able to illustrate some general relationships of food preference and dietary selectivity among various wild and domestic herbivores.

Preferences for live and dead from the various forage functional groups by the w^{th} herbivores species have been represented as vector p_w. When multiple herbivorous species other then steers are present, a composite row vector of preference for forage functional groups P is formed as:

$$P = \frac{\sum_{w=1}^{k} p_w d_w n_w}{DW} \qquad (17)$$

Herbivores express preference for location within a grazing area. Preferred locations for grazing may be determined by many factors such as herbage density, water availability, relief, slope, elevation, exposure, natural and artificial barriers, herd social interactions, climate, and prior experience. Within any rangeland, vegetation in favored locations is utilized first and often more heavily than is desirable, while less-favored locations receive little attention. Cattle prefer lowlands or bottom lands over benches and uplands, and use slopes or sidehills to a lesser extent (Nagle and Harris 1966, Julander 1958, Julander and Jeffery 1964, Cook 1966, Senft et al. 1980). Herbivores other than cattle may exhibit different preferences for location while grazing, because they are less constrained by fences, water and other manmade features used to control grazing of domestic livestock and are apparently less likely to be influenced by terrain.

Water availability is often an important influence on pattern and effort of grazing, especially on arid and semiarid rangelands. Winchester and Morris (1956) reported a positive correlation between food intake and water intake. Lange (1969) characterized the grazing pattern in relation to water. On an arid Australian rangeland with limited water, the pattern of sheep trails tends to be radial outward from water with alterations in the pattern due to terrain, fences and natural barriers. Sneva et al. (1973) experimentally varied the distance cattle had to walk from pasture to water. When water was readily accessible, cattle drank twice daily then rested and ruminated nearby. When they had to travel 1.6 km or more from rangeland to water, they drank only once daily. Productivity of the cattle was reduced when they drank only once daily. Beck (1978) reported that vegetation use by cattle in New Mexico pastures was not greatly affected by distances of up to three km from water; however, there was a trend for greater use of vegetation within 0.8 km of water. Hodder and Lowe (1978) used aerial observations of large, open Australian rangeland to determine that little grazing normally occurred beyond five km from water.

A stylized representation which illustrates the division of a pasture into areas of presumably homogeneous use (sites) is shown in figure 7.4. In this representation, only topography and distance from the point source of water influence the definition of the sites. Sites 1, 4, and 7 are lowland sites; sites 2, 5, and 8 represent slopes; and sites 3, 6, and 9 are upland areas. Within each topographical category, the higher-numbered sites are more distant from water than lower-numbered ones. The sites may be disjointed. For example, separated sidehill and upland locations in each distance-from-water interval have the same site designation regardless of their aspect.

It is difficult to separate terrain from vegetation influence since the mesic lowland areas of a rangeland are often the most productive and usually have a longer vegetative season than drier

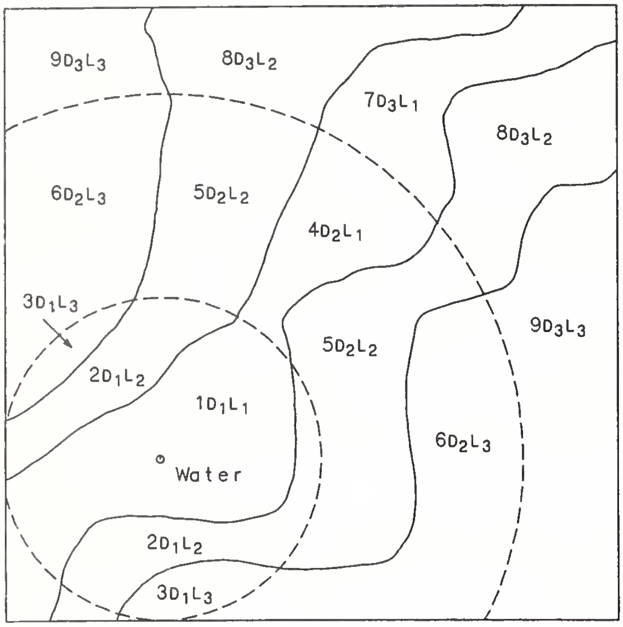

Figure 7.4
A stylized representation of a pasture divided into 9 sites based on topography and distance to water.

locations. From a comprehensive review, Arnold (1962) concluded that green forage density and grazing time affected herbage/animal interrelationships. When green-forage availability was low (less than 1000 kg/ha), grazing time increased and total intake was reduced.

The spatial distribution of grazing pressure has been simulated in a manner similar to the distribution of grazing pressure to functional groups of forage. A composite column vector of site preferences (S) is formed from the weighted average of the site preference vectors (s_w) for the individual herbivorous species other than steers. Thus:

$$S = \frac{\sum_{w=1}^{k} s_w d_w n_w}{DW} \qquad (18)$$

Up to the available amount, no physical limitations have been placed on the forage that can be harvested from a given functional group or site.

Interface of Herbage Supply and Herbivore Demand

Forage functional group and forage maturity class (live and dead) and herbage supply of carbon and nitrogen (expressed as g/m^2) generated by the plant component is converted to kilograms per site for each of the forage functional groups and maturity classes. In the following discussion, reference to herbage supply implicitly refers to aboveground biomass or carbon. Hereafter, let the matrix V represent an herbage-supply matrix.

Herbivore other than steer harvest:

$$A = DW\,S\,P \qquad (19)$$

if each element of A is less than or equal to the corresponding element of V. When some elements of A exceed the corresponding elements of V, those elements of A are set equal to the corresponding elements of V and the deficiency of forage is accumulated. The deficiency of forage is then made up from the cells of V where surplus forage was available in proportion to S * P. The plant nitrogen matrix (N) similar to V is then reduced by the fraction of biomass of each element harvested.

Herbage consumption by grazing animals rarely utilizes the total aboveground biomass except under extreme conditions. The proportion of total biomass of a particular plant which may be grazed in one day (for example, one grazing event) varies according to plant growth form and morphology, the total amount available, the herbivore species, and the herbage allowance for the grazing animals (Jameson 1963, Hyder 1972). Plants which have an erect growth form and an elevated apex contain a greater proportion of their total weight in the upper proportion of the plant and a larger proportion of the weight can be removed by a grazing event. Plants least affected by grazing have a low growth form and a large proportion of their weight concentrated in the basal portion; consequently a low proportion of the total weight is removed by grazing (Schmutz et al. 1963, Barnes 1976). Browse and other woody vegetation generally have a low removal rate by grazing. The estimation of available or grazeable browse is difficult and subject to large variation (Schuster 1965, Barnes 1976). If possible, browse species should be divided into current-annual-growth biomass and old or mature biomass and the amount of grazeable or accessible browse is some proportion of the current annual growth.

Before the attempted harvest of biomass by steers, the available biomass is reduced to account for physical limitations in forage availability and potential access to sites. These limitations are imposed by the reduction of V by the element-by-element product of V and $L_1 * L_2$, where L_1 is the column vector of physical limitations on site access and L_2 is the row vector of physical limitations on plant functional group and maturity class availability. Grazing behavior of the steer population is inferred from the product of a column vector of preference for location or site (S') and a row vector of preference for functional groups of plant species maturity classes (P'). Thus, the simulated harvest of forage by steers proceeds as outlined above for other herbivores.

The primary influence of the grazing animal upon grasslands may be related to the enhancement of nutrient cycles through the feces and urine. Ungrazed vegetation, dead material, and litter is more slowly decomposed than fecal material, and

urinary nitrogen is readily available for plant use (Dean et al. 1975, MacDiarmid and Watkin 1972, Suarez et al. 1981, Weeda 1967). Fecal and urinary deposition patterns could cause a significant redistribution of nutrients in a pasture. Petersen et al. (1956) showed that excreta distribution is not random and that at a stocking rate of 2.5 hectare per animal per year, 44.5 percent of the pasture will receive no measurable excreta while 28 percent would receive more than one excreta event. Where stock density is lower, an even more nonrandom excreta distribution would be expected. On shortgrass rangeland, Senft et al. (1980) reported that fecal pat density is related to the grazing location of cattle; however, small areas used for nongrazing activities receive the greatest density. Dean et al. (1975) measured the quantity of dietary nitrogen retained in body tissue of steers grazing shortgrass prairie to be 20 percent of that consumed. When related to total biomass production and herbage nitrogen, the proportion removed from the system was 5 to 10 percent. On highly productive pastures, the excretal return may be of little importance to the nitrogen economy (Suarez et al. 1981); whereas, on extensive rangelands it may have some importance (Dean et al. 1975).

The fraction of time spent grazing each site is computed by the analytical solution of A for S after the diet selection process is complete. The indigestible carbon fraction of the selected diet, and the nitrogen excreted (68.5 percent of N intake), are then distributed over the simulated range in proportion to the time spent grazing each site.

MODEL PARAMETERS

Estimates of biological parameters for stocker cattle growth are internally derived from asymptotic mature weight of comparable females, current weight and current age. Current average age and weight for stocker cattle should be known by an informed manager or can likely be inferred from the typical calving season in the location simulated. Asymptotic mature weight of comparable females rather than of the steers themselves is used in view of the relative abundance of reports which document mature cow size for various biological types.

Management of the stocker cattle is achieved through user-supplied number of head, date of turnout and date of roundup. Thus, the user has complete control over the stocking rate and season of use. Supplement energy can be provided in any amount for a duration defined by beginning and ending dates. The total digestible nutrient content of the supplement is assumed to be known by the user.

Preference vectors control spatial distribution of grazing pressure and the grazing pressure applied to such plant functional groups. The individual entries in the preference vectors are probabilities that a particular location or plant functional group will be used by an individual steer vis-a-vis the others available. Therefore, the elements of each preference vector must sum to one.

Physical limitations can be placed on forage availability to steers and/or access to location. The respective vectors absolutely protect a given fraction of a plant functional group or location from use. The forage availability vector may be used to protect from harvest by steers that amount of a plant functional group which is not physically available to be grazed. The most reasonable uses of the location-limitation vector are to build simulated fences which exclude all livestock from foraging in a given area, or to denote some portion of a pasture to be used as a creep to which only a fraction of the animal units have access.

Examples with various sets of parameter estimates applied in the animal component for particular hypothetical rangeland ecosystems have been presented previously (Rice et al. 1983). Additional examples are in chapter 10, part II. Parameter estimation for the animal component is discussed in chapter 7, part II.

EVALUATION

Comprehensive data sets with information sufficient for conclusive evaluation of the animal component are scarce. Data published by Harris et al. (1968) which are independent of any data used in model development have been compared to simulation results. Briefly, crested wheatgrass pastures located in the intermountain region of Utah were grazed by yearling Hereford steers from April to December. The steers were weighed periodically throughout the grazing season. Parameter estimates which conform in so far as is known to the experimental conditions were input into the model and predicted weight was monitored. Plotted in figure 7.5 are the model-predicted and observed steer cummulative weight gains for the duration of the grazing season. From April through approximately September, there is essentially no departure of simulated and observed weight changes. Later in the fall, the steers grazing this allotment made substantial weight gains presumably on fall regrowth and then lost much of that gain in November. Model predictions during the fall period are those of essentially no gain. Therefore, at the end of the grazing season, simulated weight gain was easily within the coefficient of variation (approximately 15 percent) of the average weight gain observed.

The animal component of SPUR enhances the opportunity to evaluate short- and long-term effects of rangeland ecosystem management strategies which relate to grazing. Principal avenues of livestock management are through alteration of the season of use and/or stocking rates. Grazing pressure can be tailored to particular sites with appropriate parameter estimates of livestock and nonlivestock preferences for plant materials and locations. The

use of stocker cattle (yearling steers) as economic indicators of productivity simplifies the benefit vis-a-vis cost analysis of alternative management scenarios.

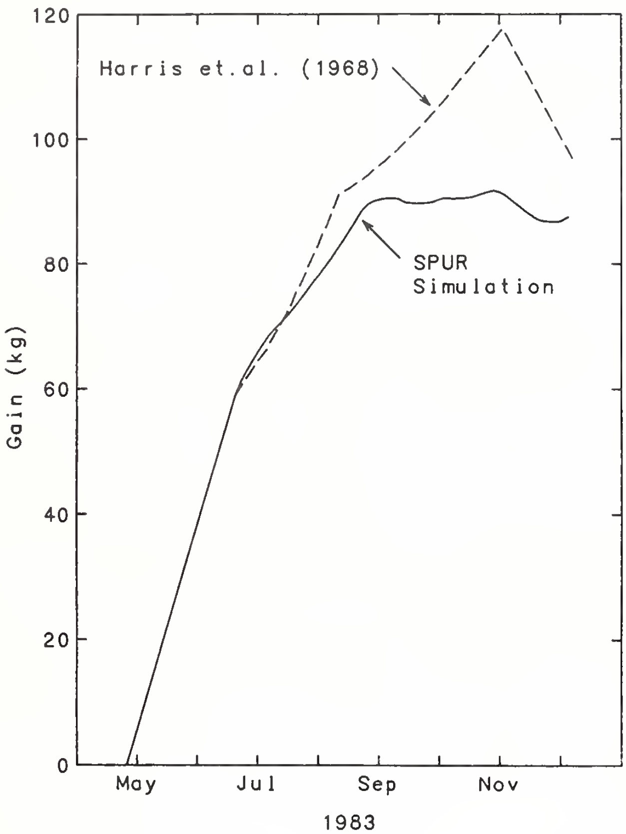

Figure 7.5
Simulated versus observed steer weight gain, April through November.

SUMMARY

The animal component of a comprehensive rangeland ecosystem simulation model has been described herein. This component should not be viewed as a finished product. Enhancements which permit more flexibility in simulated cattle management need to be included. Additionally, some aspects of the component model are based on empirical notions about the system outputs, without sound theoretical underpinnings. The description of some of the biological phenomena should include additional theory for accuracy.

The component model has utility in assessment of the costs and benefits associated with grazing appropriately simulated rangeland resources. Season-long gains in steer weight have been predicted closely corresponding to those observed in independent tests of the model.

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8. ECONOMICS COMPONENT

E.B. Godfrey, L.A. Torell

INTRODUCTION

The economics component of SPUR, like most economics models, uses biological/physical relationships as the basis for evaluation. The other model components of SPUR that have been described in the preceding chapters drive the economics component. Therefore, any errors in the preceding components will be reflected in this portion of SPUR. Most of the information needed for the economics component is not part of SPUR but must be derived external to the model.

AN OVERVIEW OF ECONOMIC ANALYSIS

Economics is concerned with the allocation of scarce resources among competing interests. An economic analysis is, therefore, primarily concerned with what difference(s) in costs and returns will occur if the allocation of resources is altered. The basic principles involved in these evaluations are outlined in numerous sources in the literature and will be reviewed briefly here. Readers interested in more detail should consult any text on benefit-cost analysis or capital budgeting (for example, Gittinger 1982, Palm and Qayum 1985, Prest and Turvey 1965, Mishan 1971, Barry et al. 1983, Godfrey and Torell 1984).

Benefit-cost analysis is a technique used to evaluate management and investment alternatives; it has been used to evaluate numerous types of range improvements for at least 25 years. A complete benefit-cost analysis will include an estimate of all costs and benefits. The criterion used to determine the "worth" of a project is whether the benefits are greater than the costs of the project or action. The basic criteria used in the economics component of SPUR are summarized in the following expressions:

$$B = \sum_{t=0}^{n} \sum_{i=1}^{m} \frac{b_{it}}{(1+r)^t} \tag{1}$$

and:

$$C = \sum_{t=0}^{n} \sum_{i=1}^{m} \frac{c_{it}}{(1+r)^t} \tag{2}$$

where:

- B = present value of the benefits (b_i) over time (t),
- C = present value of the costs (c_i) over time (t),
- t = time, from 0, 1, ... n,
- i = benefit or cost of type i, from i = 1, 2, ..., m,
- b_{it} = benefit of type i at time t = amount of response (for example, AUM's) times the value per unit,
- c_{it} = cost of type i at time t = the units of expense (for example, miles of fence) times the value per unit, and
- r = the discount rate.

The discounted benefits (1) can be greater than, less than, or equal to the discounted costs (2).

The benefits and costs included in the analysis will generally vary by the accounting stance taken. For example, ranchers could use the model to evaluate only costs they would have to bear when compared with the benefits they expect to receive. Agency administrators may, however, want to take a broader or social perspective by including all benefits and costs irrespective of who paid the costs or received the benefits. All benefits and costs are discounted to a common point in time (the present) using an appropriate discount (interest) rate.

APPLICATION IN SPUR

The economic analysis in SPUR is a simple application of benefit-cost analysis because the benefits and costs included in SPUR are limited to (1) gross returns or benefits, (2) costs and net returns, or (3) benefits.

The only benefits included in SPUR are attributable to livestock production. The model assumes the livestock that graze the forage are "stockers." Gross returns are computed as the value of beef coming from the pastures simulated in the model. The economic component uses the output from the livestock component to determine the final sale weight of animals using the site(s) simulated in the model. This ending weight is multiplied by a sale price to determine the value of the livestock produced.

The costs included in the model are the cost of stockers used to graze the pastures, the fee and nonfee costs of using these pastures, and any other costs (for example, interest paid on the animals) that must be incurred to obtain the benefits.

Net benefits at a point in time are derived by subtracting the costs from the gross benefits. The following example will help clarify the procedure used. Suppose the following assumptions are made:

1. Fifty animals are placed on the pasture(s) being simulated.
2. The animals weigh 270 kg each when purchased and placed on the pastures.
3. The animals gain an average of 46 kg (an output from the animal component) during the period considered. A 3-month grazing period is assumed.
4. The cost of purchasing these steers is $1.44 per kg.

5. The sales price of these animals is $1.39 per kg.

6. The fee and nonfee costs of raising these animals is $9.00 per head per month.

7. The interest charge for these animals for the 3-month grazing period is $14.50 per head.

This yields the following:

Costs

Feeders

50 head times $389 per head (270 kg times $1.44/kg = $389) equals	$19,450

Fees and nonfees

50 head times $9 per head times 3 months equals	$ 1,350

Interest

50 head times $14.50 per head equals	$ 725
Total costs	$21,519

Returns

Gross

50 head (no death loss assumed) times $439 per head ((270 kg plus 46 kg gain) times $1.39 per kg) equals	$21,950

Net

Gross returns ($21,950) less costs ($21,525) equals	$ 425

All costs and benefits are discounted on a daily basis. The first day of grazing during the first year any of the simulated pastures are grazed is assumed to be the present. This point in time is used as the basic reference point. All benefits and costs are discounted to this point in time. Net returns represent a return to the fixed factors of production (land, labor, and the management of the land resource).

The SPUR economic component does not use the $425 net return directly in the evaluation because the costs and returns are assumed to occur at different points in time. All costs are assumed to occur at the start of the grazing season while benefits (gross returns) are assumed to be received at the end of the grazing period. If a short grazing period is used, this makes little difference but a longer season will result in some dIfference when costs and returns are discounted to present value. If the costs and returns are obtained and paid at the same point in time, net returns in the example will be $425. However, returns are assumed to be received 3 months after costs have been incurred; therefore, net returns, after discounting, are less than $425.

The economic component in SPUR generates a common measure of economic efficiency called net present value (NPV). This is summarized in the following equation:

$$NPV = \sum_{t=0}^{n} \sum_{i=1}^{m} \frac{b_{it} - c_{it}}{(1 + r)^t} \quad (3)$$

Net present value represents a commonly used benefit/cost evaluation criteria. The discounted value of benefits minus costs must be greater than zero for the action to be economically efficient. The NPV provides a useful piece of information in determining an economically efficient allocation of resources. However, most economic analyses will involve the comparison of different NPV's. These different NPV's are derived from separate runs of SPUR that have been designed to reflect various management and improvement alternatives.

PROBLEMS OF APPLICATION

The preceding NPV criteria have the appearance of being very straight forward and easy to understand. Unfortunately, obtaining the necessary information is not as easy as one might expect. As a result, care must be used in developing the data for the economic component because most of the data must be generated outside of SPUR. Some of these problems are discussed below.

Cattle Prices

It is not obvious what cattle prices to use. Both a purchase and a sale price must be chosen. Cattle prices normally fluctuate widely over time. If data are available, one will use the price that is expected to exist at the time the animals are purchased or sold. Unfortunately, reliable price estimates are rarely available very far into the future. One is, therefore, forced to take a different approach. The most widely accepted procedure is to find the average price at the time of purchase or sale using a 3- to 5-year period. These prices are then used for the analysis by assuming that these relative "real" prices will remain constant through the period of analysis.

Once purchase and sale prices have been chosen, gross receipts and the cost of stockers purchased are calculated within SPUR. The user must specify the beginning weight of the animals. This value is then used to derive the cost of purchased animals and is used as the starting point for the animal-component simulation. The animal component provides estimates of the amount of gain and ending weight of the grazing animals. The ending weight is used to calculate gross returns.

Discount Rate

There are few issues in all economic literature that have been discussed as widely as the issue of what discount rate to use in evaluating long-term projects (for example, Baumol 1968, Fisher and Krutilla 1975, Ferejohn and Page 1978, Hanke et al. 1975, Haveman 1969, Marglin 1963, Mendelsohn

1981, Row et al. 1981). It is generally agreed that when real prices (exclusive of the rate of inflation) are used (as is done within the SPUR economic component), a real and not a nominal rate of interest should also be used. However, considerable controversy exists concerning the degree of risk and uncertainty that should be reflected in the discount rate. Most observers suggest that a real, risk-free rate be used and that the degree of uncertainty associated with the physical responses be reflected in the measurement of the benefits and costs. Row et al. (1981) estimated this long-term, risk-free rate to be about 3 to 4 percent.

Fee and Nonfee Costs of Grazing

Recent studies have indicated that the fees charged for using public as well as many private lands represent only a portion of the total cost of using rangelands (Torell et al. 1986, Obermiller and Lambert 1984, Bartlett et al. 1984). Total variable costs and not just the fees charged (Torell et al. 1986) must be used in the economic component if realistic estimates are to be obtained.

Ranking Alternatives

Considerable discussion has been focused on the problems of ranking projects. Several criteria have been suggested and used over time. These include payback period, internal rate of return, simple rate of return, a ratio of benefits to cost (benefit:cost ratio), and NPV. It is generally conceded that NPV (the criteria used in SPUR) gives the most consistent ranking. However, if different time periods are used in the analysis, some adjustment must be made for these differences (see the discussions in Barry et al. 1983, Mishan 1971, Workman 1981).

The SPUR model can be used to rank alternative range improvement or management practices by modeling the various alternatives and comparing the resultant NPV's. Given adequate funds and no alternative investments (for example, stock market, money market, bonds) that yield higher returns, the rational resource planner would invest only in those programs that yield a positive NPV. If several alternatives have positive NPV's, the resource manager should generally choose the one having the largest NPV.

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9. SENSITIVITY ANALYSIS[1/]

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INTRODUCTION

Successful use of the SPUR model requires knowledge of a large number of driving variables, parameters, and initial conditions. These quantities, which are exogenous to the model, are known with varying precision. Therefore, to identify the conditions which are important to the successful implementation of SPUR, a sensitivity analysis was conducted. Knowledge of the conditions to which the model is sensitive enables a better understanding of the model itself.

Identification of sensitive (or insensitive) parameters also suggests that the corresponding part of the Central Plains Experimental Range (CPER) grassland ecosystem might also be sensitive (or insensitive). However, the expectation of complete conformity between sensitivity analysis results and biological reality is naive, since models are merely abstractions of imperfect knowledge. If the represented part of the CPER grassland ecosystem is known to be sensitive (or insensitive), a similar observation of model sensitivity serves as a qualitative validation of the model. Areas of disagreement indicate important areas on which to concentrate future research and subsequent modification of the model. Most important are the areas where knowledge of the biology of the shortgrass prairie ecosystem is not sufficient to assess the observed sensitivity of that ecosystem to parameter perturbations. Fruitful, future field research efforts lie in these areas.

METHODOLOGY

At the beginning of the sensitivity analysis, several indicators which reflect the state of the model and the model response to perturbations were identified. These are the largest amount of standing green material generated on a single day, referred to as peak standing crop (PSC), on a per-species basis; the highest nitrogen (N) to carbon (C) ratio (N/C) for any day of a year, on a per-species basis; plant shoot death, summed over the year, on a per-species basis; assimilated carbon per plant species, summed over the year; the summed effect of soil moisture on photosynthesis on a per-species basis (termed EMP, this variable has a value of 1.0 on days when the plant encounters no moisture stress); mineralized nitrogen, summed over the year, on a per-site basis; total weight gain over the grazing season for an average steer; forage intake summed over the grazing season for an average steer; and total runoff for the site over the course of a simulated year. The approach employed here is more extensive, but otherwise generally similar, to the approach of Steinhorst et al. (1978) in the analysis of ELM.

Unfortunately, the initial release of the field-scale SPUR model does not meet the objective of simulation of annual runoff from pastures. Consequently, the sensitivity of simulated annual runoff to perturbation of parameters and initial conditions was not examined.

In all stages of the SPUR sensitivity analysis, each model run began in 1971 on day one (Jan. 1) and ended on day 365 (Dec. 31) of 1975. Actual weather data from the Central Plains Experimental Range, with the exception of daily wind run, were used. (Wind run was generated using a separate procedure (Haan 1977)). The sensitivity indicators were measured in the fourth and fifth simulated years to enable the model to adjust for any disequilibrium in initial conditions.

Sensitivity of a perturbed condition was expressed as a ratio, either:

$$Z = \frac{\sum_{i=1}^{n}(S_i - \hat{S}_i)^2}{\sum_{i=1}^{n} S_i^2} \qquad (1)$$

or:

$$R = \frac{Z}{\dfrac{\sum_{j=1}^{m}(P_j - \hat{P}_j)^2}{\sum_{j=1}^{m} P_j^2}} = \frac{Z\sum_{j=1}^{m} P_j^2}{\sum_{j=1}^{m}(P_j - \hat{P}_j)^2} \qquad (2)$$

where Z denotes absolute sensitivity, S denotes the vector of state variables indexed by i, R denotes relative sensitivity, and P denotes the vector of model parameters and initial conditions indexed by j. Hats over vector representations indicate perturbed vectors as opposed to nominal states.

In stage one, the hypothesis of dynamic similarity of simulated functional groups of forages (warm-season grasses, cool-season grasses, warm-season forbs, cool-season forbs and shrubs) was examined. The sensitivity indicators applicable to functional groups of plant species were measured separately for each of the simulated functional groups. Parameters applicable to each functional group were collected into a macroparameter (table 9.1). Important first-order-interaction effects, indicative of dynamic dissimilarity among the functional groups, were of primary interest. Each of the macroparameter main effects was confounded with a fourth-order interaction effect and each first-order interaction effect was confounded with a third-order interaction effect. Second-order interaction effects were confounded with other

[1/]Adapted from M.D. MacNeil, J.W. Skiles, and J.D. Hanson. 1985. Sensitivity analysis of a general rangeland model. Ecological Modelling 29:57-76. The authors acknowledge G.S. Innis for assistance in planning the sensitivity analysis.

Table 9.1
Composition of macroparameters and conditions examined in stage-1

Macroparameter	Definition	Value	
		Nominal	Perturbed
1.A	Maximum photosynthesis rate in mg CO_2/h (MPR) for warm-season grasses.	75	93.8
	Optimum temperature in °C for photosynthesis (OTP) for warm-season grasses.	30	37.5
	Temperature in °C for initiation of translocation from roots to shoots (TRS) for warm-season grasses.	10	7.5
1.B	MPR for cool-season grasses	35	26.3
	OTP for cool-season grasses	20	15.0
	TRS for cool-season grasses	5	3.8
1.C	MPR for warm-season forbs	45	56.3
	OTP for warm-season forbs	30	37.5
	TRS for warm-season forbs	9	11.3
1.D	MPR for cool-season forbs	17	12.8
	OTP for cool-season forbs	20	15.0
	TRS for cool-season forbs	5	3.8
1.E	MPR for shrubs	10	7.5
	OTP for shrubs	20	15.0
	TRS for shrubs	5	3.8
	Maximum-minimum temperature	(°C) read daily	x 0.70
1.F	Precipitation	(cm) read daily	x 0.70
	Solar radiation	(ly) read daily	x 0.70

second-order interaction effects and were termed residual effects.

Multivariate analysis of variance procedures were used to ascertain the effects of model perturbations on the series of 5 x 1 vectors of sensitivity indicators when separate measurements were made on each functional group of plant species. Univariate analysis of variance procedures were used to ascertain the effects of model perturbations for indicators that were characteristics of the site being simulated and when only one functional group of plant species was included. The analyses were then averaged over years, analogous to whole plot analyses in split-plot statistical models. Time trends in the sensitivities were also examined.

The second stage of the sensitivity analysis was designed to examine the response of the SPUR model without grazing to changes in model parameters, driving variables and initial conditions. Only one functional group of plant species (warm-season grasses) was simulated in stage two. Therefore, more parameters could be examined than if functional-group-specific parameters had been included. Macroparameters were formed of supposedly independent parameters, driving variables and initial conditions (table 9.2). Main effects were confounded with third- and higher order interaction effects, while first-order interactions were confounded with second- and higher order interaction effects. The experiment was designed as a one-fourth replication of a 2^8-factorial experiment.

After identification of macroparameters which resulted in large alterations of model outcomes when perturbed, an additional experiment was conducted to more definitively identify those parameters, initial conditions and their interactions to which the model is sensitive. This experiment was a 1/128 replication of a 2^{13}-factorial experiment comprised of the parameters contained in macroparameters 2.B, 2.E, and 2.H. Some first-order interactions were, of necessity, confounded with other first-order interactions. However, when a set of confounded first-order interactions appeared important, separate 2^2-factorial experiments were conducted to ascertain the importance of each confounded two factor interaction. All effects were confounded with second- and higher order interactions which were assumed to be of negligible importance. Except for time trends, data from both experiments

Table 9.2
Composition of macroparameters and conditions examined in stage-2

Macroparameter	Definition	Value	
		Nominal	Perturbed
2.A	Maximum photosynthesis rate	75.0	93.8
	Wind knockdown	.00010 km	.00008
	Decomposition ψ 1/	8.0 bars	6.0
	Initial soil water	.050	.038
2.B		45.0 °C	33.8
	Plant activity curve parameters	30.0 °C	22.5
		7.0 °C	5.3
	Precipitation knockdown	-.25 cm	-.32
	Dark respiration rate	.323 mg CO_2/h	.242
	ψ for translocation from root to shoot (TRS).	-12.0 bars	-9.0
2.C	ψ for maximum photosynthesis	20.0 bars	25.0
	Respiration-temperature coefficient	.0677 °C	.0846
	Maximum nitrogen-uptake rate	.0020 mg/h	.0015
	Initial dead roots	610 g/m^2	763
	Initial live roots	417 g/m^2	521
2.D	Proportion biomass for TSR	.70	.53
	Proportion biomass for TRS	.015	.019
	Dead-root decomposition	.10	.13
	Initial litter	147 g/m^2	110
	Condition-I curve number	60	54
2.E	Root:shoot ratio	10.0	12.5
	Leaf area conversion	.015 m/g	.019
	Frost kill temperature	-2.0 °C	-1.5
	Initial inorganic N	.10g/m^2	.13
2.F	Green death proportion	.04	.03
	ψ for respiration	-.115 bars	-.144
	Root death proportion	.003	.004
	Initial organic matter	2000 g/m^2	1500
2.G	Root respiration rate	.0025 mg CO_2/hr	.0031
	Day senescence begins	June 28	Aug. 12
	Litter decomposition rate	.15	.19
	Root depth	18.0 cm	22.5
	Soil characteristics 2/		
2.H	TRS temperature	10.0 °C	7.5
	Organic matter decomposition rate	.004	.003
	Initial standing dead	90.0 g/m^2	67.5
	Soil evaporation parameter	.13	.12
	Day senescence ends	Sept. 26	Dec. 2

1/ ψ = water potential
2/ soil characteristics:

	nominal			perturbed		
	layer 1	layer 2	layer 3	layer 1	layer 2	layer 3
porosity	0.463	0.463	0.463	0.347	0.347	0.347
1/3-bar water potential	.093	.113	.113	.070	.085	.085
15-bar water potential	.040	.054	.054	.030	.041	.041
saturated-soil conductivity.	.50	.25	.10	.38	.19	.08

conducted at stage two of the sensitivity analysis were analyzed as indicated for the univariate sensitivity indicators in stage one.

The sensitivity of the SPUR model with grazing by steers was evaluated in a third stage of this analysis. A subset of parameters, driving variables and initial conditions to which the model was either sensitive or insensitive in stage two and parameters and initial conditions applicable to the steer-growth component were examined (table 9.3). The design was similar to the 1/2 replication of a 2^4-factorial experiment employed in stage one. In addition to the sensitivity indicators previously used in stages one and two, daily steer weight gain and intake were accumulated over the grazing season in stage three. The data were again analyzed as indicated for the univariate indicators in stage one.

RESULTS AND DISCUSSION

The sensitivity analysis conducted on the SPUR model was a test of model response to perturbation of driving variables, parameters and initial conditions. To reduce the sensitivity analysis into manageable problems, a series of hypotheses were formed. In each case, the outcome of the hypothesis test (stage) determined the structure of the subsequent stage.

Dynamic Similarity of Functional Groups of Forages (Stage 1)

An apparent lack of interaction among macroparameters 1.A, 1.B, 1.C and 1.D in stage one indicated similarity in the dynamic response of simulated grasses and forbs to alteration of theoretical maximum photosynthetic rate, optimum temperature for photosynthesis and temperature for initiation of carbohydrate translocation from roots to shoots. Interactions of macroparameters 1.A through 1.D with macroparameter 1.E were more important than the interactions among macroparameters 1.A through 1.D. The interactions of macroparameters 1.A through 1.D with macroparameter 1.E have two plausible interpretations. First, simulated shrubs might be dynamically different than simulated grasses and forbs. Alternatively, the dynamic responses of simulated grasses and forbs might depend on minimum and/or maximum temperatures. As all functional groups are modeled

Table 9.3
Composition of macroparameters and conditions examined in stage-3

Macroparameter	Definition	Value: Nominal	Value: Perturbed
3.A	Maximum photosynthesis rate	75.0 mg CO_2/h	56.0
	Root depth	18.0 cm	23.0
	Maximum and minimum temperatures	read daily	x 1.05
	Green/dead preference for forage	9:1	2.08:1
3.B	ψ for translocation from roots to shoots.	-12.0 bars	-15.0
	Nitrogen-uptake rate by plants	.0020 mg/h	.0015
	Asymptotic steer weight	475 kg	594 kg
3.C		45.0 °C	34.0
	Plant activity curve parameters	30.0 °C	23.0
		7.0 °C	5.0
	Condition-I curve number	60.0	75.0
	Digestibility equation slope	2.4	3.0
	Age of steers at turnout	400 days	500 days
3.D	Root:shoot ratio	10.0	8.5
	Frost kill temperature	-2.0 °C	2.5
	Steer turnout date	May 15	May 5
3.E	Critical temperature for translocation from roots to shoots	20.8 °C	7.5
	Soil evaporation parameter	.13	.16
	Date to remove steers from pasture	Oct. 15	Oct. 5
3.F	Day senescence ends	Sept. 26	Dec. 2
	Precipitation	read daily (cm)	x 0.75
	Stocking rate	40 hd/640 A	50 hd/640 A
	Weight of steers at turnout	140 kg	238 kg

with one set of equations in which different parameter sets are employed and no interactions among macroparameter 1.A through 1.D are observed, the latter interpretation seems more plausible. The dynamic similarity of simulated forage species functional groups suggested that only one functional group would be required for further stages of the sensitivity analysis. Therefore, stages two and three were conducted using warm-season grasses as the only simulated plant species. The use of one functional group rather than five enabled the more complete examination of the plant and animal components in these subsequent stages.

The years 1974 and 1975 differed in temperature and precipitation during the growing season with 1974 being relatively warm and wet. Interactions of macroparameters 1.A through 1.E with simulated years and interactions of these macroparameters with macroparameter 1.F containing precipitation and solar radiation parameters were noted for plant-related sensitivity indicators. It appears that the two sets of interactions closely parallel each other. From the mimicry of interactions with simulated years by interactions with macroparameter 1.F, we concluded that further monitoring of time trends in sensitivity was unnecessary. This also suggested any disequilibrium in initial conditions had been overcome by the fourth simulated year and that differences among simulated years without grazing were largely due to differences in precipitation, temperature, and solar radiation.

In-depth Testing of the Plant Component (Stage 2)

Stage two of the analysis evaluated the responsiveness of the SPUR model without grazing. Macroparameters and interactions which exhibited the greatest relative effects on state variables are presented in table 9.4. Macroparameters 2.B, 2.E, and 2.H and interactions among them were judged most important to the sensitivity of the model as a whole. To verify some of the intuitive evaluation of individual parameters and their interactions, component parameters were examined in a follow-up analysis. The component parameters from macroparameters 2.B, 2.E, and 2.H and interactions that had the largest relative effects on state variables are indicated in table 9.5. Diagnosis of causal component parameters from macroparameters other than 2.B, 2.E, and 2.H is subjective.

Macroparameters 2.B, 2.E, and 2.H and interactions of macroparameters 2.B and 2.H with macroparameter 2.E had the greatest effect on simulated peak standing crop. Subsequent analysis of component parameters only partially identified the causal effects. When the plant activity curve parameters (see macroparameter 2.B in table 9.2) were at the nominal level, peak standing crop was highly sensitive to a reduction of the day senescence ends, with peak standing crop markedly reduced as a result. When the parameters of the plant activity curve were reduced, peak standing crop was relatively insensitive to the day senescence ends. Additionally, peak standing crop was about equally sensitive to reduction of the organic matter decomposition rate and increases in the leaf area conversion parameter. An interaction of parameters corresponding to the observed interaction of macroparameters 2.B and 2.E was not detected. The inability to detect such an interaction is suggestive of higher order interactions among the component parameters.

The peak N/C was affected by macroparameters 2.E and 2.H as well as interactions 2.B * 2.E, and 2.E * 2.H. The interaction of macroparameters 2.E and 2.H resulted in peak N/C being greatly increased when 2.E was perturbed with 2.H at the nominal level and slightly reduced when 2.H was perturbed. Interaction effects among component parameters corresponding to the observed interactions of macroparameters were relatively minor. The critical temperature to initiate translocation from roots to shoots predominated the components of macroparameter 2.H and all other parameters. Minor mediation of the effect of the critical temperature to initiate translocation from root to shoot on peak N/C by the plant activity curve parameters was also noted. Maximum N/C was increased when the critical temperature to initiate translocation from roots to shoots was increased, and the effect was somewhat greater when the plant activity curve parameters had been reduced.

The sensitivity of year-long integrated mineralized soil N was most affected by macroparameters 2.B and 2.E and the 2.B * 2.E interaction. Lesser effects were noted for interactions 2.B * 2.H and 2.E * 2.F. In terms of model states, the effect of 2.E * 2.F was relatively small. The interaction of the plant activity curve parameters with day senescence ends accounted for much of the variation observed among the macroparameters and their interactions. Mineralization of soil N was increased when the day senescence ends was reduced with the plant activity curve parameters held at their nominal level. However, a small reduction in the mineralization of soil N was noted when the plant activity curve parameters were perturbed.

Perturbation of macroparameters 2.E, 2.B, and 2.H affected integrated plant death. The interaction of 2.B with 2.E was of similar magnitude as the effect of 2.B. The 2.E * 2.F and 2.B * 2.H interactions were of lesser magnitude, but also important. Plant death was markedly reduced when macroparameter 2.E was perturbed. However, a similar reduction was not found when component parameters were examined in greater detail. Thus, two explanations for the dramatic effect of macroparameter 2.E remain. Either three or more components of macroparameter 2.E interacted to radically alter plant death or one of the components of 2.E interacted with the initial standing dead or organic matter decomposition rate. The interaction of day senescence ends and the plant activity curve predominated the supplemental analysis with the effect of organic matter decomposition rate also being important. Causing senescence to end later, with the plant activity curve at the nominal level, markedly reduced plant death. However, when the plant activity curve

Table 9.4
Stage-2 macroparameters and interactions which exhibited the greatest relative effects on the state variables[1]

PSC	PNC	MN	DTH	CA	EMP
2.E (58%)	2.E (50%)	2.E (13%)	2.E (64%)	2.B (12%)	2.E (21%)
2.B (7%)	2.E * 2.H (35%)	2.B * 2.E (12%)	2.B (5%)	2.B * 2.E (12%)	2.E * 2.H (17%)
2.B * 2.E (6%)	2.H (8%)	2.B (11%)	2.B * 2.E (5%)	2.C * 2.D (10%)	2.B (14%)
2.H (5%)	2.B * 2.E (4%)	2.E * 2.F (8%)	2.E * 2.H (3%)		2.B * 2.E (13%)
2.E * 2.H (4%)		2.B * 2.H (6%)	2.H (3%)		2.B * 2.H (6%)

[1]State variables are abbreviated: PSC = peak standing crop; PNC = maximum nitrogen:carbon ratio; MN = integrated year-long mineralization of nitrogen; DTH = integrated year-long plant death; CA = integrated year-long carbon assimilation; and EMP = integrated year-long effect of soil moisture on net photosynthesis.

Table entries are the macroparameter designations (table 9.2) with the percentage of total variation accounted for by the effect shown in parentheses.

Table 9.5
Stage-2 component parameters for macroparameters B, E, and H and interactions which exhibited the greatest relative effects on the state variables[1]

PSC	PNC	MN	DTH	CA	EMP
A (34%)	E (66%)	A * M (29%)	A (38%)	A (31%)	A (35%)
A * M (28%)	A * E (10%)	A (79%)	A * M (27%)	L (9%)	A * M (29%)
M (19%)		M (19%)	M (19%)	D (6%)	M (23%)
F (2%)				M (5%)	
G (2%)				F (5%)	
				H * L (5%)	

[1]State variables are abbreviated: PSC = peak standing crop; PNC = maximum nitrogen:carbon ratio; MN = integrated year-long mineralization of nitrogen; DTH = integrated year-long plant death; CA = integrated year-long carbon assimilation; and EMP = integrated year-long effect of soil moisture on net photosynthesis.

Table entries are the parameter designations: A = plant activity curve parameters; C = dark respiration rate; D = ψ for translocation from root to shoot (TRS); E = TRS temperature; F = organic matter decomposition rate; G = leaf area conversion; H = root:shoot ratio; J = frost kill temperature; K = initial inorganic N; L = soil evaporation parameter; M = day senescences ends; N = initial standing dead; and shown in parentheses, the percentage of total variation accounted for by the effect.

parameters were reduced, perturbations of the day senescence ends increased plant death slightly.

In comparison with other indicator variables, carbon assimilation appeared generally less sensitive to perturbation of the macroparameters. Only macroparameter 2.B and the 2.B * 2.E and 2.C * 2.D interactions of macroparameters seemed of major importance. The interaction of macroparameters 2.C and 2.D was manifest as an increase in carbon assimilation when macroparameter 2.C was perturbed with 2.D at the nominal level, but the depression in carbon assimilation that resulted when 2.D was perturbed alone was not buffered by joint perturbation of 2.C with 2.D. The plant activity curve parameters and the water potential for translocation from roots to shoots were identified as components of macroparameter 2.B which affected carbon assimilation. In addition, soil evaporation and the day senescence ends in macroparameter 2.H also affected the sensitivity of carbon assimilation. The interaction of water potential for translocation from roots to shoots and initial inorganic nitrogen resulted in carbon assimilation being increased when either was perturbed singly, but reduced when both were simultaneously perturbed. When the soil evaporation parameter was reduced or the day senescence ends was increased, carbon assimilation was reduced since the effect of the day senescence ends was four times larger than the effect of perturbing the soil evaporation parameter.

The effect of moisture on photosynthesis, EMP, was sensitive to perturbation of macroparameters 2.B and 2.E as well as the interactions 2.B * 2.E, 2.B * 2.H and 2.E * 2.H. When macroparameter 2.E was perturbed with 2.B at the nominal level, EMP was reduced. However, when macroparameter 2.E and 2.B were perturbed jointly, no effect on EMP was noted. Perturbation of macroparameter 2.B increased EMP when macroparameter 2.H was held at both the nominal and perturbed level. The 2.B * 2.H interaction arose because the response to perturbation of 2.B was reduced by over half when 2.H was also perturbed. Perturbation of both macroparameters 2.E and 2.H increased EMP. However, the simultaneous perturbation of both 2.E and 2.H resulted in EMP being increased about one-third less than would be expected if the effects of 2.E and 2.H were additive. When individual parameters were examined, the interaction of plant activity curve parameters with the day senescence ends was identified as having a major effect on EMP. Reduction of the plant activity curve parameters with the day senescence ends at the nominal level markedly increased EMP. When the day senescence ends was increased, changes in the plant activity curve parameters had little effect on EMP.

Livestock and the Effects of Grazing (Stage Three)

In stage three, the response of animal-component outputs and the modification of previously observed plant- and hydrologic-component indicators by grazing were of primary interest. Therefore, comparisons between nominal and perturbed conditions within stage three and comparisons of stage three results with those obtained in stage two are indicated. Macroparameters and interactions that exhibited the greatest relative effects on state variables are shown in table 9.6.

Stage two results lead to the expectation that plant activity curve parameters and the day senescence ends would interact in stage three. However, macroparameters 3.C and 3.F did not interact to affect the sensitivity of peak standing crop. Only the effects associated with macroparameters 3.C and 3.E had substantial effects on peak standing crop. Perturbation of macroparameter 3.C resulted in increased peak standing crop, in agreement with the average effect of reduced plant activity curve parameters observed in stage two. Peak standing crop had been apparently insensitive to the critical temperature for translocation from root to shoot in stage two. Since it is doubtful that the date livestock were removed affected peak standing crop, it might be concluded that increased soil evaporation caused the observed reduction in peak standing crop which resulted when macroparameter 3.E was perturbed.

Maximum N/C was sensitive to macroparameters 3.B, 3.C, and 3.E and the 3.B * 3.E interaction. No effect associated with macroparameter 3.B or the interaction of 3.B and 3.E was found in the inspection of the state variables. This result suggests a possible higher order interaction affecting peak N/C. In stage two, an increase in maximum N/C was observed when the critical temperature for translocation from root to shoot was increased. Here, a reduction in peak N/C, presumably due to a reduced critical temperature for translocation from root to shoot, was observed when macroparameter 3.E was perturbed.

Macroparameters 3.C, 3.D, and 3.E and the interaction of 3.C with 3.E affected the sensitivity of mineralized soil N. However, the effects on state variables were always less than 4 percent. Much larger effects had been observed in the absence of grazing.

Integrated season-long plant death was sensitive to perturbation of macroparameters 3.C and 3.E and interactions of 3.B * 3.F, 3.C * 3.D, and 3.C * 3.E. However, interaction effects on state variables were small, relative to the main effects. Perturbation of macroparameter 3.E markedly reduced plant death. When macroparameter 3.C was perturbed, plant death increased. A similar response had been noted when the macroparameter which contained the plant activity curve parameters was perturbed in stage two.

In contrast to stage two, perturbation of macroparameters in stage three had notable effects on integrated season-long carbon assimilation. Major effects were observed when macroparameters 3.C, 3.D, or 3.E were perturbed. When macroparameter 3.C was perturbed, carbon assimilation was increased, again similar to the increase observed when the plant activity curve parameters were perturbed in stage two. Perturbation of

Table 9.6
Stage 3 macroparameters and interaction that exhibited the greatest relative effects on the state variables[1]

PSC	PNC	MN	DTH
3.C (51%)	3.C (48%)	3.C (36%)	3.C (50%)
3.E (22%)	3.B (12%)	3.E (14%)	3.E (21%)
3.C * 3.E (6%)	3.E (11%)	3.C * 3.E (4%)	3.C * 3.E (15%)
	3.B * 3.E (11%)	3.C * 3.D (3%)	3.D (11%)
	3.B * 3.F (3%)		
CA	**EMP**	**FI**	**AW**
3.C (58%)	3.C (37%)	3.C * 3.E (21%)	3.C * 3.E (21%)
3.E (13%)	3.F (16%)	3.C (14%)	3.E * 3.F (15%)
3.D (5%)	3.E (14%)	3.E (13%)	
	3.C * 3.E (8%)	3.B * 3.D (13%)	
		3.B * 3.E (7%)	
		3.A * 3.C (6%)	

[1] State variables are abbreviated: PSC = peak standing crop; PNC = maximum nitrogen:carbon ratio; MN = integrated year-long mineralization of nitrogen; DTH = integrated year-long plant death; CA = integrated year-long carbon assimilation; EMP = integrated year-long effect of soil moisture or net photosynthesis; FI = integrated season-long forage intake by a steer; and AW = cumulative season-long daily weight change.

Table entries are the macroparameter designations (table 9.3) with the percentage of total variation accounted for by the effect shown in parentheses.

macroparameter 3.E was manifest as a reduction in carbon assimilation. Carbon assimilation was reduced when macroparameter 3.D was perturbed.

The main effects associated with macroparameters 3.C, 3.E, and 3.F affected EMP as did the 3.C * 3.E interaction. The variable EMP was reduced when macroparameter 3.C was perturbed and increased when 3.E or 3.F was perturbed. The result associated with macroparameter 3.C is difficult to explain in light of stage two. The apparent effects are opposite of those anticipated if they are assumed to be due to reduction of the plant activity curve parameters.

Integrated intake by steers was sensitive to a variety of main effects and interactions. Variables that had affected forage quantity or quality indicators also affected intake. The main effects of macroparameters 3.C and 3.E had sizable impacts on simulated, integrated, season-long intake. Macroparameter 3.C interacted with macroparameters 3.A and 3.E and macroparameter 3.B interacted with macroparameters 3.D and 3.E. The effect of diet digestibility on intake is quite clear in the animal model and corresponds to the main effect associated with macroparameter 3.C. Previous results would indicate a lesser quality forage available in a reduced amount when macroparameter 3.E was perturbed. Thus, a greater proportion of the grazing season would be spent when diet digestibility is affected by the slope parameter. The interaction of macroparameters 3.C and 3.A is somewhat more bothersome. Macroparameter 3.A had no detected effects on forage quantity (PSC or CA) or quality (PNC). Therefore, it might appear that the relative preference for green versus dead plant material would interact with the slope parameter from the increasing phase of the digestibility equation. The reduction of intake when 3.A was perturbed (reduction being smaller when 3.C was also perturbed than when 3.C was at the nominal level) fits this hypothesis. Explanations of the 3.B * 3.D and 3.B * 3.E interactions are not readily apparent.

While the system of effects governing intake seemed highly sensitive, the manifestations of intake differences in weight change were somewhat buffered. Interactions of macroparameters 3.C and 3.F with macroparameter 3.E affected cumulative daily weight change. The slope of the increasing phase of the equation to predict total digestible nutrients from carbon and nitrogen and stocking rate were probably the principal components of macroparameters 3.C and 3.F, respectively, which contribute to the observed interactions. When the slope parameter was increased, more highly-digestible diets would result and a more rapid increase in steer weight would be expected (Maynard et al. 1979). The mechanism by which the increased diet digestibility effect was mediated by macroparameter 3.E is open to some speculation. However, the indicated mechanism which alters intake could lead to the observed result.

Perturbation of macroparameter 3.F led to reduced, cumulative, season-long weight change. A similar effect would be expected from increased stocking rate (Hart 1978). The interaction of stocking rate with reduced forage quantity or quality has also been alluded to previously (Hart 1978).

The apparent insensitivity of cumulative season-long weight change to changes in the length of grazing season is noteworthy. However, steers were turned out early in the year and when they were turned out even earlier, only a low quality diet was attainable. Removal of steers from pasture was late in the year and as with date of turnout, only a low quality diet would be available. Given the low quality diet available, steers would be expected to have daily weight change near zero.

The lack of sensitivity of cumulative, season-long weight change to green/dead preference for forage was not anticipated. A better system to quantify selectivity of steers among forage parts probably needs to be developed.

SUMMARY

Taken as a whole, the SPUR model does not seem overly "fragile" to parameter perturbations. Perhaps it is not even as fragile as the ecosystem it simulates. The plant and hydrology components seem too independent. Greater sensitivity of plant growth indicators to parameters which influence soil-water dynamics was anticipated. With the model in its present form, plant activity curve parameters for each functional group of plant species should be known with a reasonable degree of accuracy. The Julian day on which senescence is to end may also be important in the simulation of plant growth depending on grazing intensity. The plant and animal components interact with the parameters employed in one component, ultimately affecting the other. Plant nitrogen dynamics and steer intake and growth respond to the critical temperature for translocation from root to shoot. Parameters which convert percent nitrogen to diet energy density must also be known accurately to simulate livestock performance and control recycling of nitrogen.

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1. INTRODUCTION TO THE SPUR USER GUIDE

J. W. Skiles

INTRODUCTION

The purpose of the chapters presented in Part II of this publication is to give the user enough information to operate either the field-scale version or the basin-scale version of the SPUR model. The field-scale version of SPUR is designed for analysis of rangeland hydrology, plant and animal dynamics, and range management practices on a field or pasture scale. Conceptually, there is no limit to the size of a pasture. The decision to use either the field-scale version or the basin-scale version of the SPUR model depends on whether the pasture has streamflow channels on it and whether the user has adequate information about these channels. If the answer to either of these questions is no, then the user should probably use the field-scale version. It should be borne in mind that while the basin-scale version of SPUR provides detailed information about the simulated watershed, it gives less resolution of the results produced by the plant and animal components.

The chapters that follow will aid the user in assigning values for parameters and initial conditions. Chapters 2 and 3 are the guides for the field-scale and basin-scale versions of the SPUR model, respectively. The input requirements and the output options for these two versions of the model are discussed there. In chapter 4, information for using the climate generator and for using the climate parameter calculator program is presented. Chapters 5, 6, and 7 give guidelines for estimating parameters and initial conditions for the plant component, the hydrology, soils, and snowmelt portions of the hydrology component, and the animal component, respectively. Field-scale version and basin-scale version errors are reported in Chapters 8 and 9, respectively. These chapters should be consulted when either of the SPUR program codes produces errors when reading the three initialing files. Chapter 10 contains the maps and tables necessary for estimating the parameters for using the climate generator. Example data sets and the resultant SPUR output for those data sets for the field-scale version are found in chapter 11. Chapter 12 gives example data sets and output for the basin-scale version. Lastly, chapter 13 is a glossary of terms used in this document.

Each chapter in the Documentation and User Guide was written to essentially stand by itself. While this means that there is some repetition in the contents of some chapters, this will facilitate the use of the program codes because the user will be turning back and forth less between chapters.

The user needs to become thoroughly familiar with either chapters 2 or 3, depending on whether he is using the field-scale or the basin-scale version of the model. This will enable the user to gain an understanding of the model as to complexity and resolution of the different components. These chapters are the actual guides for building the data files used by SPUR and for directing the output generated by the model. These two chapters also contain extensive flowcharts of each module in the SPUR codes. The flowcharts may be skipped by the casual user, but are included for reference to demonstrate program execution and control.

STRUCTURE OF THE PROGRAM CODES

The computer code released for this phase of the SPUR project is an agglomeration of at least four previously developed computer codes and one new code. Algorithms incorporated into the hydrology routines in SPUR came, in part, from CREAMS (Knisel 1982) and from SWRRB (Williams et al. 1985). The snowmelt and snow accumulation routines came from HYDRO-17 (Anderson 1973). The beef production routines came from the Texas A & M University model developed by Sanders (Sanders and Cartwright 1979). The rangeland autotroph production and growth routines are new and are from Hanson et al. (1986) and verified in Skiles et al. (1982). Additionally, economics, other heterotrophs (wildlife), and input/output routines have been developed around these codes and algorithms.

The two project modelers associated with SPUR have added to the programs and used their programing techniques to bring these codes together and assemble them into a working computer program. This method of construction is the "bottom-up" approach to model building (Innis et al. 1980) which starts with isolated and independent high-resolution and complex process models. These are gathered and melded into a total systems model. This approach, advocated by Holling (1966) and others, means high confidence may be placed in the separate process models. It also means that fewer validation experiments are required of the total model since its parts have been tested and validated separately. This may be true with some modeling projects, but it can present problems as mentioned below.

The modules of each of these cited models are arranged in alphabetically in the programs. The name of each module generally describes the processes which are modeled in that module. Because of the alphabetical arrangement, however, all plant-component modules (for example) are not adjacent in the program listings.

Units and Word Representation

Portions of the hydrology models incorporated into the SPUR program codes are designed to use input parameters with English units (for example, cubic feet per second or acre feet) and produce output with those same units. The animal component, the

plant component, and portions of the hydrology component (snowmelt) use metric units. Each component also contains coefficients which reflect the particular unit system with which they were constructed. When intermediate variables are calculated in a component under one unit system and then passed to another component with a different unit system, it means that they must be converted from one unit system to another. If these variables are passed in COMMON statements, they may again need to be converted when they are passed to the next component. This is a result of the bottom-up method of model construction. As long as the user remains aware that these trans formations are taking place and as long as the user enters the information required by the model in the proper units, the user should not experience difficulty.

Depending on word size and word representation of the computer the user is using, he or she may have some difficulty in matching the sample output given in either chapters 11 or 12. As an example, suppose the user sets a cut-off value for a variable at 25.0. This variable is checked in each time step and an execution pathway is changed if the variable exceeds the cut-off value. The check is accomplished through the use of an IF statement in the program which says, "if the variable is greater than 25.0, pass program control a different way, otherwise continue on as before." The simulation proceeds for some time and at time step, say 254, the variable reaches a value of 25, but the user's machine represents that value as 25.0 while the machine which produced the results being compared represents it as 24.99999. In the first instance, the IF statement returns a TRUE for the test while in the second instance, the test is FALSE. This means that at time step 254, one machine directs execution one way and the other machine does not. The result, even though the initial conditions and parameter files are identical, is two output files with two distinct sets of output variables.

Testing has shown that over a simulation of more than one year (depending on the output variables studied) these differences amount to more than a discrepency in the fifth decimal place; they can be significant. The SPUR codes have been developed on a machine with a 32-bit architecture. Comparisons with 8-bit and 16-bit machines have shown that conditions such as those described above occur primarily in the conversions of units between one model component and another (and in some of the trigonometric functions). The user must make allowances for the problems caused by word size and word representation.

Characteristics of the Models

The two versions of the SPUR model, the field-scale and the basin-scale versions, share some of the same subroutines. The subroutine USER, for example, reads the three initialization files and does most of the error checking of the input variables in both versions. There are major differences between the two version of the SPUR model, which are discussed below.

Comparison of the Two Versions of SPUR

The field-scale version of SPUR is composed of approximately 4,000 lines of FORTRAN code. The basin-scale version of the model is about 4,500 lines long. The basin-scale program is about one-third comment cards while the field-scale program is about 27 percent comment cards. The field-scale program requires about 317 blocks of disk storage (1 block equals 512 bytes) for the source code and 182 blocks for the executable image. The basin-Scale program requires 359 blocks and 257 blocks of storage for the source code and the executable image, respectively.

Both codes have been developed on a computer with virtual memory. During execution, the field-scale version of the code requires a maximum of 387 virtual memory pages while the basin-scale version requires 524 pages. A virtual memory page is the equivalent of one block.

The field-scale version of SPUR has been tested with a 10,000-acre pasture, but there is no limitation to the size of the field to be simulated. It may simulate one square meter for the smallest sized pasture. Generally, field sizes of about 2,000 acres are the most tractable.

The field-scale version may simulate one field that may be divided into no more than nine sites, making the site the smallest unit that may be simulated with this version of the model. Each site may have up to eight soil layers, however, the upper two layers must each be 3 inches (7.5 cm) in depth. Also, the lowest or last layer must be free of roots.

The basin-scale version of SPUR can simulate up to 27 fields, 1 pond, and 9 channels. A watershed may not be larger than ten square miles in total area. The field is the smallest unit that may be simulated with this version of the model. Each field must be linked to a channel. Each field may have up to eight soil layers, with the same restrictions that apply to the field-scale program pertaining here too. The basin-scale program can accommodate distributed rainfall within the simulated basin.

Both versions of the model operate on a daily time step, though some processes within the model (snowmelt, photosynthesis) use increments of time that are smaller than one day. The smallest increment of time for which either version of the model may produce output is one day. (This may be changed if the user makes changes in the program code.)

Each version of the SPUR code can simulate a maximum of seven plant species. For any given simulation experiment, a minimum of one plant species must be used. One variety of steer may be used in either program but simulations may be done without grazing steers. Up to 10 wildlife species may be incorporated in a simulation experiment. Simulations may be done with either version of the model without wildlife or steers or with wildlife and no steers.

Table 1.1 summarizes the computer characteristics and the model characteristics of the field-scale and the basin-scale versions of the SPUR model.

Table 1.1
Comparison of the field-scale version and the basin-scale version of SPUR

	Field-scale version	Basin-scale version
Computer characteristics		
Number of lines	3,964	4,493
Number of comment cards	1,062	1,499
Source code size	317 blocks[1/]	359 blocks
Executable image size	182 blocks	257 blocks
Maximum memory during execution	387 pages[2/]	524 pages
Model characteristics		
Time step	one day	one day
Number of fields	1	27
Number of sites	9	-
Number of soil layers per site	8	-
Distributed rainfall option	no	yes
Number of soil layers per field	-	8
Number of channels	-	9
Number of ponds	-	1
Number of plant species per simulation	7	7
Number of steer varieties per simulation	1	1
Number of wildlife species per simulation	10	10

1/ One block equals 512 bytes.
2/ One virtual memory page equals approximately 512 bytes.

Times for Computer Experiments

A total of 45 simulation experiments with the field-scale version of SPUR were done to give the user an idea of what the costs, in terms of central processor unit (CPU) time, are for the simulation of different combinations of initial conditions, soil layers, sites, grazing steers, and so forth. All time tests were done on a Digital Equipment Corporation VAX 11/750 with two megabytes of memory, operating under VMS 3.4, and with a floating-point accelerator board installed. (The VAX 11/750 is a medium sized minicomputer in terms of execution speed with about 5 million floating-point operations per second as it was configured for these tests (Dongarra 1984)).

The simulations were done when only system processes were in operation so that virtual memory paging charged to the timing jobs was held to a minimum. The three files required to initialize the model and the climate file were stored on a mass storage device and available for direct access by the machine executing the program. Each experiment was for one year.

Results of the simulation tests for the field-scale version of the model are shown in table 1.2. Only if the users have the same configuration for their machines, should they expect to obtain these times for these same experiments. The values shown in table 1.2 are meant as guides for the user.

The first series of experiments, numbers 01 through 07, tested the time requirements for adding a single plant species up to the maximum of seven for which the code is dimensioned. The same plant species parameters were used for each additional species. The tests were done with one simulated site and four soil layers. The base simulation took 31 seconds. Addition of each plant species took on the order of seven additional seconds for an increment of about 23 percent more time over the base simulation time o, 31 CPU seconds per plant species added.

A series of experiments (numbers 08 through 11) shows that addition of soil layers, to the maximum of eight, costs less than one CPU second. The addition of sites to a simulation experiment is much more costly. Experiments 12 through 20 show that each new site costs 13 CPU seconds with an increase of about 42 percent over the base simulation time of 31 CPU seconds for each site added. This series was done with a single plant species and each site had the same four soil layers.

Experiments 21 through 29 tested the costs of using five plant species with the addition of more sites. These species used were those parameterized in table 5.3, Part II. Each site had the same four soil layers. As may be seen, using more than one plant species on a site requires much CPU time. The increase can be more than 72 percent over the base simulation time of 61 CPU

Table 1.2
Central Processor Unit (CPU) time, in seconds, required for 45 different simulation experiments done with the field-scale version of SPUR. Time is rounded to the nearest second

Experiment number	Conditions of the simulation	CPU time (sec)	Delta CPU time (sec)	Percent increase from base simulation
01	1 site, 4 soil layers, same 1 plant, no grazing	31	-	
02	1 site, 4 soil layers, same 2 plants, no grazing	38	7	
03	1 site, 4 soil layers, same 3 plants, no grazing	45	7	
04	1 site, 4 soil layers, same 4 plants, no grazing	52	7	23
05	1 site, 4 soil layers, same 5 plants, no grazing	59	7	
06	1 site, 4 soil layers, same 6 plants, no grazing	65	6	
07	1 site, 4 soil layers, same 7 plants, no grazing	72	7	
08	1 site, 5 soil layers, 1 plant, no grazing	32	-	
09	1 site, 6 soil layers, 1 plant, no grazing	32	0	3
10	1 site, 7 soil layers, 1 plant, no grazing	33	1	
11	1 site, 8 soil layers, 1 plant, no grazing	33	1	
12	1 site, 4 soil layers, 1 plant, no grazing	31	-	
13	2 sites, 4 soil layers, 1 plant, no grazing	44	13	
14	3 sites, 4 soil layers, 1 plant, no grazing	57	13	
15	4 sites, 4 soil layers, 1 plant, no grazing	70	13	
16	5 sites, 4 soil layers, 1 plant, no grazing	83	13	42
17	6 sites, 4 soil layers, 1 plant, no grazing	96	13	
18	7 sites, 4 soil layers, 1 plant, no grazing	109	13	
19	8 sites, 4 soil layers, 1 plant, no grazing	122	13	
20	9 sites, 4 soil layers, 1 plant, no grazing	135	13	
21	1 site, 4 soil layers, 5 different plants, no grazing	61	-	
22	2 sites, 4 soil layers, 5 different plants, no grazing	105	44	
23	3 sites, 4 soil layers, 5 different plants, no grazing	147	42	
24	4 sites, 4 soil layers, 5 different plants, no grazing	191	44	
25	5 sites, 4 soil layers, 5 different plants, no grazing	233	42	72
26	6 sites, 4 soil layers, 5 different plants, no grazing	275	42	
27	7 sites, 4 soil layers, 5 different plants, no grazing	319	44	
28	8 sites, 4 soil layers, 5 different plants, no grazing	360	41	
29	9 sites, 4 soil layers, 5 different plants, no grazing	405	45	
30	1 site, 4 soil layers, same 5 plants, no grazing	59	-	
31	2 sites, 4 soil layers, same 5 plants, no grazing	98	39	
32	3 sites, 4 soil layers, same 5 plants, no grazing	138	40	
33	4 sites, 4 soil layers, same 5 plants, no grazing	178	40	
34	5 sites, 4 soil layers, same 5 plants, no grazing	220	42	66
35	6 sites, 4 soil layers, same 5 plants, no grazing	257	37	
36	7 sites, 4 soil layers, same 5 plants, no grazing	297	40	
37	8 sites, 4 soil layers, same 5 plants, no grazing	336	39	
38	9 sites, 4 soil layers, same 5 plants, no grazing	381	45	
39	1 site, 4 soil layers, 1 plant, steers	34	-	
40	1 site, 4 soil layers, 2 different plants, steers	43	9	
41	1 site, 4 soil layers, 3 different plants, steers	50	7	
42	1 site, 4 soil layers, 4 different plants, steers	59	9	26
43	1 site, 4 soil layers, 5 different plants, steers	67	8	
44	1 site, 4 soil layers, 6 different plants, steers	78	11	
45	1 site, 4 soil layers, 7 different plants, steers	85	7	

seconds. The nonuniform time increments shown in table 1.2 are due to paging during the job as the machine processed plants with different phenological characteristics and to paging caused by system processes.

Experiments 30 through 38 show that using the same plant species over several sites is not as expensive as using different plant species, but the costs can be considerable. A time increment of about 66 percent over the base simulation time of 59 CPU seconds can be expected.

Only grazing by the steer component was tested, since wildlife may be placed on the simulated field at any time of the year and they may graze any of the forage species in any combination. Hence, a standard wildlife grazing test could not be formulated. Generally, the addition of a wildlife consumer costs less than one second per site per year simulated.

Experiments 39 through 45 indicate that while grazing steers the addition of forage species can add about 26 percent more time to the simulation over the base cost of 34 CPU seconds. Since the steers graze the forage species preferentially, and since each plant species has a different phenology, the program execution pathways are somewhat different and, therefore, the time increments shown in the table are not uniform.

Addition of fields and/or plants to simulation experiments with the basin-scale version of the SPUR model result in about the same percentage increase in time as is shown in table 1.2 for the field-scale program. A standard experiment with the basin-scale program using five plant species all growing on three fields linked by a single channel costs about 164 CPU seconds. Since there are many more combinations of fields and channels available for simulation with the basin-scale program, no further timing experiments with it were done.

Communication Between Program Modules

Communication between program modules (subroutines and function subprograms) is accomplished primarily through the use of labeled block COMMON statements. There are 35 block common statements in the main program of the basin-scale version of SPUR and 33 block common statements in the main program of the field-scale version of SPUR. Each of these COMMON statements appears at least once in other modules of the program code. Some variables are passed as formal arguments in the CALL statements, but these are held to a minimum.

The second module in each version of the SPUR code is a block data module called COMBLK. In this module, the variables passed in the block COMMON statements are assigned values at compile time. This module is included in both versions of SPUR for those users with nonzero-based computers. The function of this module is to initialize the variables in the COMMON statements. For those users with zero-based machines, this module can be deleted. However, the user should be sure to initialize those variables which are not set to zero in COMBLK; these variables should be initialized in DATA statements in the main program.

EXPERIMENTING WITH THE CODE

Once the selected program is loaded, compiled, and ready for operation, the user must be sure the program can access the three initializing files, the climate file, and also a scratch file. The user should next try to match the example output shown in chapter 11 for the field-scale version or chapter 12 for the basin-scale version. Once the differences between user output and source output have been reconciled, the user should decide what simulations he or she wishes to perform and which variables influence the perturbations he or she wishes to introduce into the system.

The user, after first establishing the scenario to be explored with the model, must then review the appropriate chapters in Part II to determine what parameters and initial conditions to supply for the scenario. The SPUR model requires a large number of input variables to operate, any one of which can be changed by the user and the ramifications of the change on the modeled system explored. The user should then review the information available from the literature or the field for values which can be used as parameters and initial conditions for the model. Next, the user should determine those parameters and initial conditions for which he or she has no information, using the guidelines set forth in other chapters in Part II.

After values for all the parameters and initial conditions have been established, the user then must place these values in the appropriate files in the proper format. Information for constructing these files is in chapter 2 for the field-scale version of SPUR and in chapter 3 for the basin-scale version.

That done, the user should then experiment with the model, adjusting those parameters for which he or she has no information, until the time traces produced by the model match those, within some confidence interval, that he is using as a reference. In the absence of reference time traces, the user should decide on the shape and amplitude of the curves he wishes to produce with the model and experiment with the model until the desired results are produced. The simulation experiment which produces the desired results is termed the "standard" or "nominal" experiment or simulation. Once this standard is established, the user may then perturb the system being simulated by changing the parameters and/or initial conditions, in a controlled and orderly manner, to study the response of the system to those perturbations.

BEFORE USING THE PROGRAM

Each user of the SPUR model no doubt has some idea or opinion as to how a given rangeland system will respond to perturbations. The user, therefore,

has a conceptual "model" of how the system operates. Further, the user has an idea or an opinion of how a simulation model of the system should behave; a model of the model. Part II discusses a possible circumstance wherein a difference might occur between what the user's model predicts and what the SPUR model predicts and the reason for the difference.

The user should know that the SPUR model is an ecosystem level model. A change in one abiotic variable or state variable to perturb the system may cause counterintuitive behavior of the model and signal apparent errors in its conceptualization. However, ecosystems are assemblages of species which interact with each other and their environment in many diverse and complex ways. The SPUR model reflects these interactions and the user should keep this in mind.

To illustrate this point, assume the user has tuned the model to simulate a specific locale. Further, assume the user wishes to perturb the ecosytem by decreasing the amount of solar radiation supplied to the model. He or she does this by multiplying that driving variable, read by the code on a daily basis, by 0.75, giving the model only 75 percent of the nominal solar radiation. The unexpected result is an increase in plant productivity, a circumstance which has actually occurred in some of the early model testing.

Given this unexpected result and given that the plant component includes the explicitly modeled process of photosynthesis, the user must revise his simulation scenario. The problem here is not with the simulation model or its formulation. The user, or rather the user's model of the model, has failed to realize that solar radiation not only drives photosynthesis, but it also influences soil evaporation. A decrease in solar radiation does, in fact, reduce photosynthesis, but such a decrease also causes less evaporation, meaning reduced stress on the plant roots. This in turn means a more vigorous shoot initiation for the plant in the spring and a greater initial leaf biomass to photosynthesize. The result, owing to this better start, is increased plant productivity.

Realizing that decreased solar radiation would affect the other driving variables, a better experiment might include decreasing daily minimum and maximum temperatures, thereby simulating a more realistic abiotic condition; a decrease in solar radiation would not occur alone. This circumstance is another result of the bottom-up approach to model construction.

The lessons learned here are the planning of experiments ahead of time is essential; counterintuitive results can occur and should possibly even be expected; an understanding of the system to be modeled and of the model is necessary before the SPUR model can be used effectively.

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2. USER GUIDE FOR THE FIELD-SCALE VERSION

J.W. Skiles, E.P. Springer

INTRODUCTION

This chapter describes the tasks necessary to operate the field-scale version of the SPUR program. These tasks include organizing the input data files which initialize the hydrology and soils component, the snow accumulation and snowmelt routines, the plant component, and the animal and wildlife components. Also discussed are the output control switches that direct the SPUR program to produce various files detailing results of simulation experiments. The program organization and the flow charts for the subprograms are presented. Tables which give the name, record number, and format field for each variable read by the SPUR program are shown in this chapter.

PROGRAM ORGANIZATION

The field-scale version of SPUR was developed in an enhanced FORTRAN IV environment of a VAX 11/750 and designed to be operated in a time-sharing, interactive mode or what some facilities call terminal batch. Most of the programing statements in the code can be compiled by standard FORTRAN IV compilers. The code is executed as a series of embedded loops, the loops controlling the counters for site, day, month, and year for the simulation experiment. The program requires four files for execution, three of which initialize the model variables and a fourth which supplies the weather data on a daily basis, one record per day.

After the particular variables are read from the three user-supplied files and the model is initialized, the program enters an outer loop which controls the year counter. This loop is processed once per year. Within the year loop, the month loop is executed next. The subroutine NDPM, which determines the number of days per month, is called each month. The month loop is executed 12 times per year. The day loop is within the month loop and is executed each simulation day, including February 29 in years with leap years. Within the day loop, the subroutine PLANT and PACK19 are called. Also, the climate record for that day is read in this loop. Within the day loop, the site loop is executed once per simulated site (to a maximum of nine sites). The subprogram FLDHYD is called once per site. Before termination of the simulated day loop, the daily report can be written to a scratch file for later printing, if the IP1 switch is set to one. This is done through a call to DAYREP. After the simulation is completed, and if IP2 is set to one, a call to YRREP is done to print out the monthly and yearly summaries for the simulation. (See the section that follows on output options.) Program flow is illustrated in figure 2.1.

Also shown in figure 2.1 are the subprograms called by the main program. These are the "level-one" subprograms; the level-zero or main program is called FSVPI for field-scale version, phase I. Table 2.1 presents the name of each subroutine or function for FSVPI. For this user guide, a subroutine subprogram or a function subprogram will be called a module. Also, a brief description of each module is given. The order in which the modules appear in table 2.1 is the same order in which they occur in the program listing.

The hierarchy of the program modules (subroutines and functions) is shown in table 2.2. The main program, FSVPI, calls those modules from the zero level of the hierarchy. Those modules in level one, in turn, call the next level of the hierarchy and so on.

Flowcharts

To aid the user in understanding SPUR program execution, 44 flowcharts have been included in this chapter. Figure 2.2 defines the symbols used in the flowcharts and figures 2.3 through 2.45 represent each SPUR program module, including a "chart" for the BLOCK DATA module. Only major calculations or decisions are shown in the flowcharts; bookkeeping and zeroing accumulators, for instance, are generally not shown.

FILE STRUCTURE

At the start of execution, through a call to the subprogram IOSET, the program will execute four input/output pairs (writes and reads) of interactive code to which the user must respond. The program asks for the file name of each initialization and definition file in turn. The user must then supply an alphanumeric string which is the name of the respective data file. The program will write the message:

ENTER FILE NAME FOR ANIMAL DATA

to which the user responds with the name of the data file which holds the information for the animal routines. The program will then ask for the climate file information by writing the message:

ENTER FILE NAME FOR CLIMATE DATA.

The user responds with the name of the file with the climate data. The program will then write:

ENTER FILE NAME FOR HYDROLOGY DATA

and the user enters the name of the appropriate data file. The last message is:

ENTER FILE NAME FOR PLANT DATA

which the user does.

This exchange is done on two logical unit numbers (LUN's); LUN 5 being the device from which the computer reads the information and LUN 6 being the device to which the machine writes the prompts.

(text continues on page 147)

Table 2.1
Module number, module name, and module description of the mainprogram and subprograms in the field-scale version of SPUR

Number	Name	Description
01	FSVPI	Main calling program, calls initializing subprograms. Contains year, month, and day loops, and sums results for later reporting.
02	COMBLK	A block common segment which contains values in data statements for variables passed in the common blocks: the values are assigned at compile time.
03	ADPL	Subprogram to calculate snow areal depletion curve.
04	AESC19	Subprogram to adjust areal snow cover based on current melt or accumulation.
05	ALBEDO	Subprogram to determine surface albedo for the day.
06	ANIMAL	Subprogram for control of animal routines.
07	ATANF	Subprogram for arc tangent function referenced by plant routines.
08	BELL	Subprogram for bell-shaped function referenced by plant routines.
09	CRACK	Subprogram to compute crack flow.
10	DAYREP	Subprogram which produces daily report.
11	DETAIL	Subprogram which produces additional model output.
12	ERR	Subprogram containing error codes for the input routines called from that routine. (See chapter 8 for a list of error codes.)
13	EVAPR	Subprogram to compute evapotranspiration.
14	FLDHYD	Subprogram to control daily soil-water balance routines and calculate surface runoff volume.
15	GROW	Subprogram to calculate steer growth and forage requirements.
16	HYP	Subprogram for hyperbolic function referenced by plant routines.
17	IOSET	Subprogram for opening files; input, output, and scratch files are opened in this routine.
18	LINE	Subprogram to control output paging, called from several places in the program depending on the print switches used.
19	LVSTK	Subprogram for control of steer growth and forage consumption.
20	MELT19	Subprogram to calculate melt for nonrain periods and 100% snow cover.
21	NDPM	Subprogram to determine number of days in the month.
22	NITE	Subprogram to simulate nitrogen dynamics in plants and soils.

Table 2.1--Continued
Module number, module name, and module description of the mainprogram and subprograms in the field-scale version of SPUR

Number	Name	Description
23	NTRFC	Subprogram to determine the amount of forage consumed. (This is the plant/animal iNTeRFaCe.)
24	PACK19	Subprogram to calculate snow accumulation and melt.
25	PERC	Subprogram to calculate percolation when water content is greater than field capacity.
26	PEXP	Subprogram to calculate peak photosynthesis rate for existing conditions for the day.
27	PHOPER	Subprogram to calculate daily photoperiod.
28	PHOTO	Subprogram to determine daily photosynthesis.
29	PLANT	Subprogram for control of plant routines.
30	PLGRO	Subprogram to simulate carbon (biomass) dynamics in plants and sites.
31	ROUT19	Subprogram to route excess water through the snowpack.
32	SOIL	Subprogram to compute current soil-water status.
33	SOILC	Subprogram to calculate soil water content versus soil-water tension curve and the lower soil water content boundary.
34	SOILM	Subprogram to calculate soil-water tension in the top soil layer and the wettest layer in the root zone for each field.
35	SOLADJ	Subprogram to adjust incoming solar radiation for slope and aspect.
36	TEMPP	Subprogram referenced by the plant routines to calculate temperatures.
37	THRESH	Subprogram for threshold function referenced by plant routines.
38	TLAPSE	Subprogram to lapse temperature if elevation of simulation site is different from elevation of site at which temperature is measured. A standard lapse rate of 6.5 °C/1000 m is used.
39	USER	Subprogram to initialize hydrology, plant, and animal components.
40	WLDLF	Subprogram to calculate demand for forage by wildlife species present.
41	YRREP	Subprogram for writing monthly and annual reports.
42	ZERO	Subprogram to zero forage-supply arrays.
43	ZERO19	Subprogram to zero snow accumulation values when snow water is depleted.

Table 2.2
Hierarchy of the calling and called modules in the field-scale version of SPUR. The numbers correspond to those shown in table 2.1

Level Number			
LEVEL 0:	1P-FSVPI	... CALLS 5F-ALBEDO, 10S-DAYREP, 11S-DETAIL, 12S-ERR, 14S-FLDHYD, 17S-IOSET, 18S-LINE, 21S-NDPM, 24S-PACK19, 29S-PLANT, 35F-SOLADJ, 38F-TLAPSE, 39S-USER, 41S-YRREP	... CALLED BY NO SUBPROGAMS
LEVEL 1:	41S-YRREP	... CALLS 18S-LINE	... CALLED BY 1P-FSVPI
	39S-USER	... CALLS 3S-ADPL, 4S-AESC19, 12S-ERR, 18S-LINE, 35S-SOILC	... CALLED BY 1P-FSVPI
	38F-TLAPSE	... CALLS NO SUBPROGRAMS	... CALLED BY 1P-FSVPI
	35F-SOLADJ	... CALLS NO SUBPROGRAMS	... CALLED BY 1P-FSVPI
	29S-PLANT	... CALLS 6S-ANIMAL, 11S-DETAIL, 27F-PHOPER, 30S-PLGRO, 34S-SOILM,36F-TEMPP	... CALLED BY 1P-FSVPI
	24S-PACK19	... CALLS 4S-AESC19, 20S-MELT19, 31S-ROUT19, 43S-ZERO19	... CALLED BY 1P-FSVPI
	21S-NDPM	... CALLS NO SUBPROGRAMS	... CALLED BY 1P-FSVPI
	17S-IOSET	... CALLS NO SUBPROGRAMS	... CALLED BY 1P-FSVPI
	14S-FLDHYD	... CALLS 32S-SOIL	... CALLED BY 1P-FSVPI
	10S-DAYREP	... CALLS 18S-LINE	... CALLED BY 1P-FSVPI
	5F-ALBEDO	... CALLS NO SUBPROGRAMS	... CALLED BY 1P-FSVPI
LEVEL 2:	32S-SOIL	... CALLS 9S-CRACK, 13S-EVAPR, 25S-PERC	... CALLED BY 14S-FLDHYD
	43S-ZERO19	... CALLS NO SUBPROGRAMS	... CALLED BY 24S-PACK19
	31S-ROUT19	... CALLS NO SUBPROGRAMS	... CALLED BY 24S-PACK19
	20S-MELT19	... CALLS NO SUBPROGRAMS	... CALLED BY 24S-PACK19
	34S-SOILM	... CALLS 11S-DETAIL	... CALLED BY 29S-PLANT
	30S-PLGRO	... CALLS 7F-ATANF, 8F-BELL, 16F-HYP, 22S-NITE, 28S-PHOTO, 36F-TEMPP, 37F-THRESH	... CALLED BY 29S-PLANT
	27F-PHOPER	... CALLS NO SUBPROGRAMS	... CALLED BY 29S-PLANT
	6S-ANIMAL	... CALLS 19S-LVSTK, 40S-WLDLF	... CALLED BY 29S-PLANT
	33S-SOILC	... CALLS NO SUBPOGRAMS	... CALLED BY 39S-USER
	4S-AESC19	... CALLS NO SUBPROGRAMS	... CALLED BY 24S-PACK19, 39S-USER
	3S-ADPL	... CALLS NO SUBPROGRAMS	... CALLED BY 39S-USER
	18S-LINE	... CALLS NO SUBPROGRAMS	... CALLED BY 1P-FSVPI, 10S-DAYREP, 39S-USER, 41S-YRREP
	12S-ERR	... CALLS NO SUBPROGRAM	... CALLED BY 1P-FSVPI, 39S-USER
LEVEL 3:	40S-WLDLF	... CALLS 23S-NTRFC	... CALLED BY 6S-ANIMAL
	19S-LVSTK	... CALLS 11S-DETAIL, 15S-GROW, 23S-NTRFC	... CALLED BY 6S-ANIMAL
	37S-THRESH	... CALLS NO SUBPROGRAMS	... CALLED BY 30S-PLGRO
	28S-PHOTO	... CALLS 26F-PEXP, 36F-TEMPP	... CALLED BY 30S-PLGRO
	22S-NITE	... CALLS 8F-BELL, 16F-HYP	... CALLED BY 30S-PLGRO
	7F-ATANF	... CALLS NO SUBPROGRAMS	... CALLED BY 30S-PLGRO
	25S-PERC	... CALLS NO SUBPROGRAMS	... CALLED BY 32S-SOIL
	13S-EVAPR	... CALLS NO SUBPROGRAMS	... CALLED BY 32S-SOIL
	9S-CRACK	... CALLS NO SUBPROGRAMS	... CALLED BY 32S-SOIL
LEVEL 4:	26F-PEXP	... CALLS 8F-BELL	... CALLED BY 28S-PHOTO
	15S-GROW	... CALLS NO SUBPROGRAMS	... CALLED BY 19S-LVSTK
	23S-NTRFC	... CALLS 42S-ZERO	... CALLED BY 19S-LVSTK, 40S-WLDLF
	16F-HYP	... CALLS NO SUBPROGRAMS	... CALLED BY 22S-NITE, 30S-PLGRO
	36F-TEMPP	... CALLS NO SUBPROGRAMS	... CALLED BY 28S-PHOTO, 29S-PLANT, 30S-PLGRO
	11S-DETAIL	... CALLS NO SUBPROGRAMS	... CALLED BY 1P-FSVPI, 19S-LVSTK, 29S-PLANT, 34S-SOILM
LEVEL 5:	42S-ZERO	... CALLS NO SUBPROGRAMS	... CALLED BY 23S-NTRFC
	8F-BELL	... CALLS NO SUBPROGRAMS	... CALLED BY 22S-NITE, 26F-PEXP, 30S-PLGRO

F represents a function subprogram, P represents the main program, S represents a subroutine subprogram.

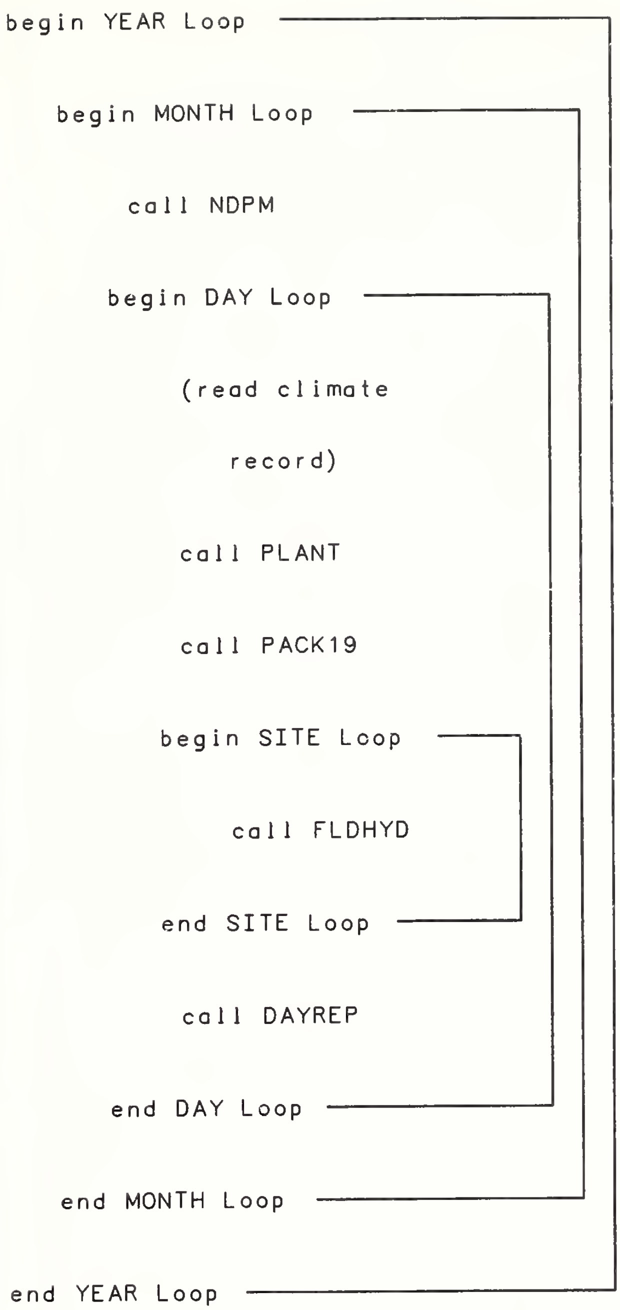


Figure 2.1
Field-scale version of SPUR:
Main program control loops.

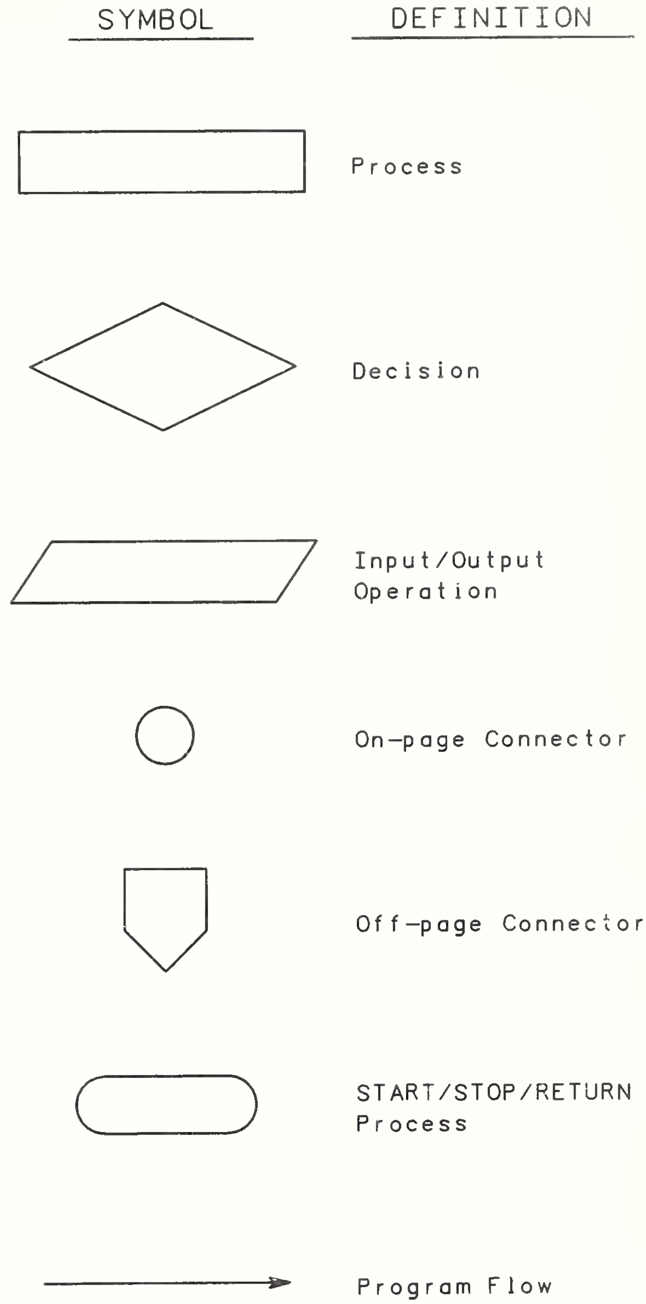


Figure 2.2
Symbols and definitions used in
flowcharts.

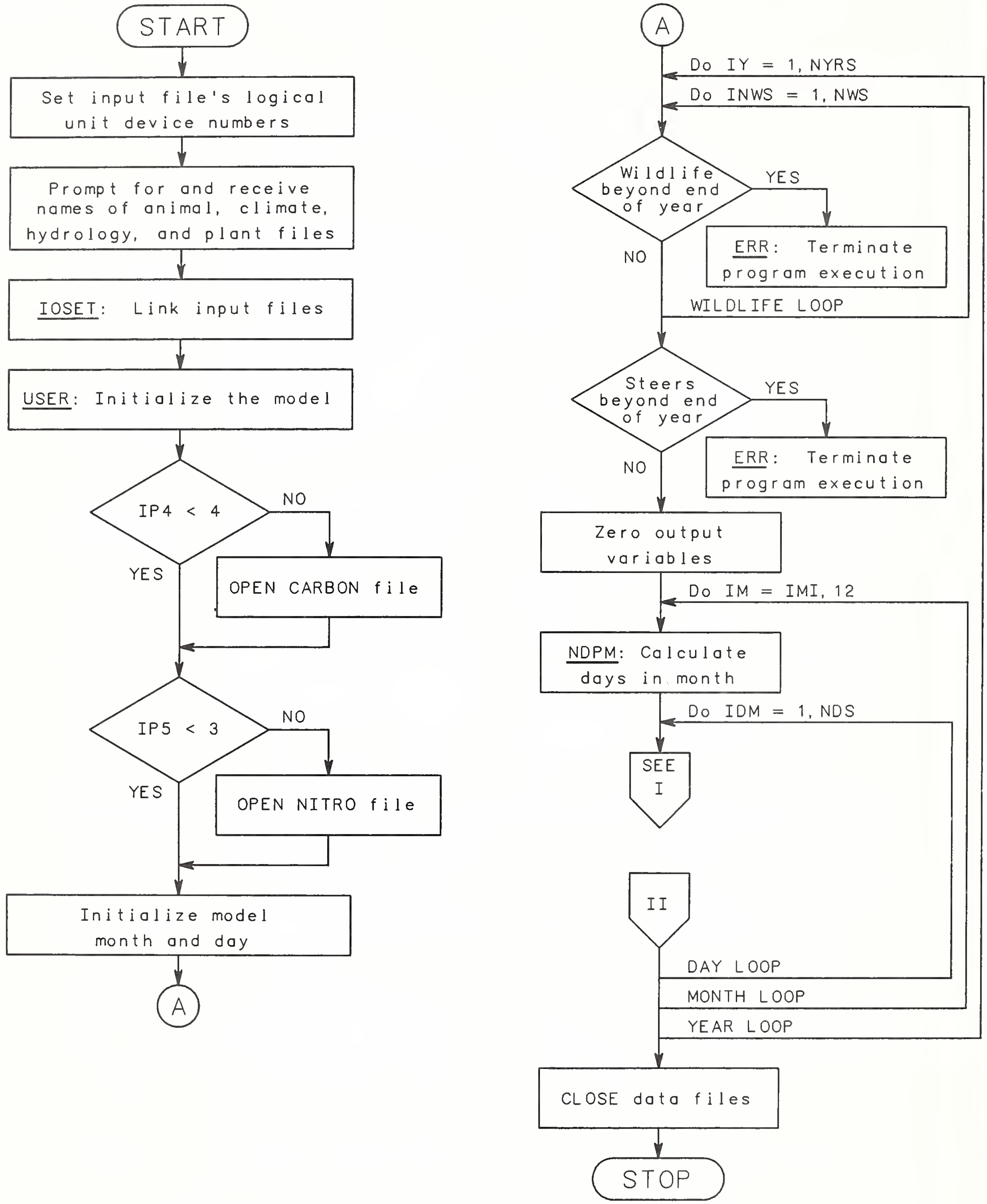


Figure 2.3
Program FSVPI: SPUR field-scale version phase I.

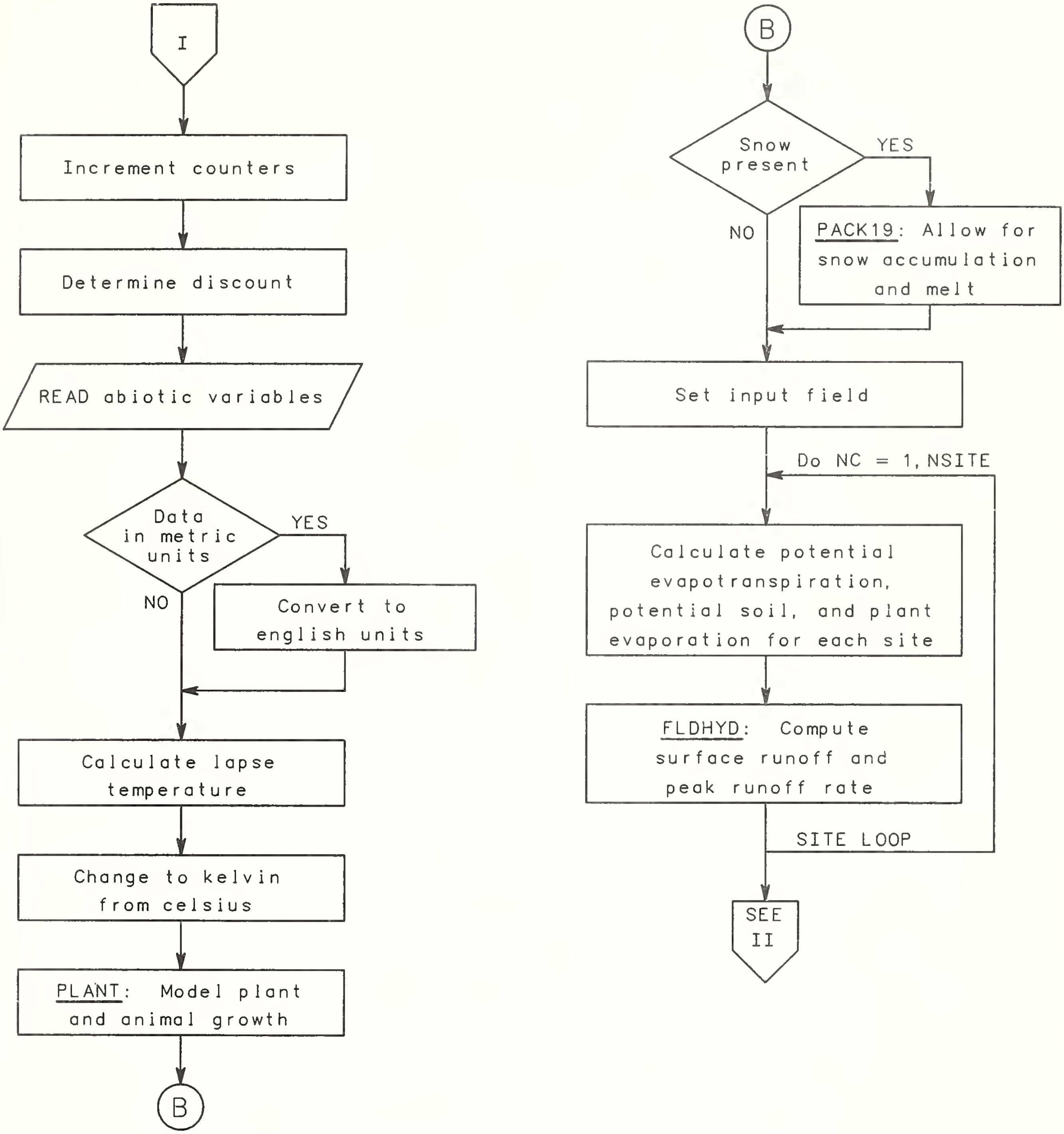


Figure 2.3--Continued
Program FSVPI: SPUR field-scale version phase I.

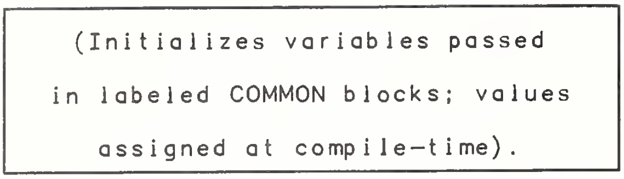


Figure 2.4
COMBLK: Initializes variables passed in labeled COMMON blocks.

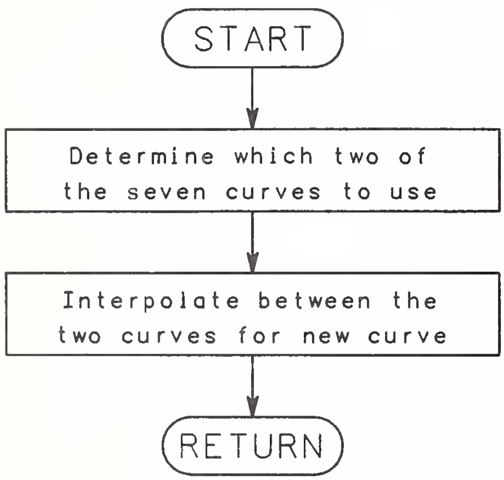


Figure 2.5
Subroutine ADPL: Determine the areal depeltion curve.

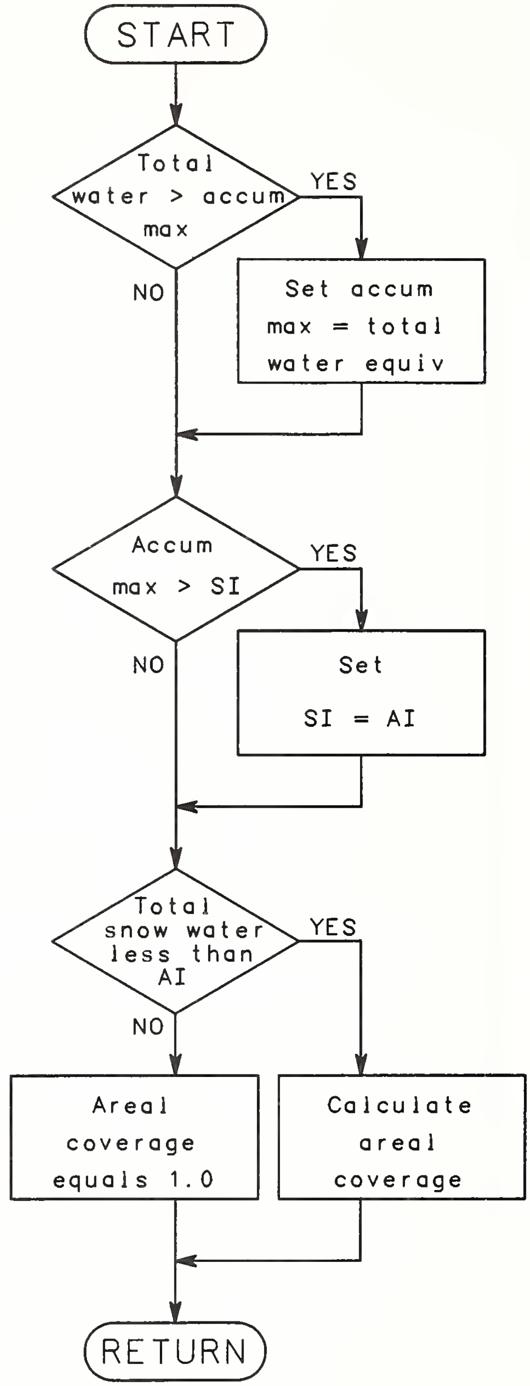


Figure 2.6
Subroutine AESC19: Compute the areal extent of snow cover.

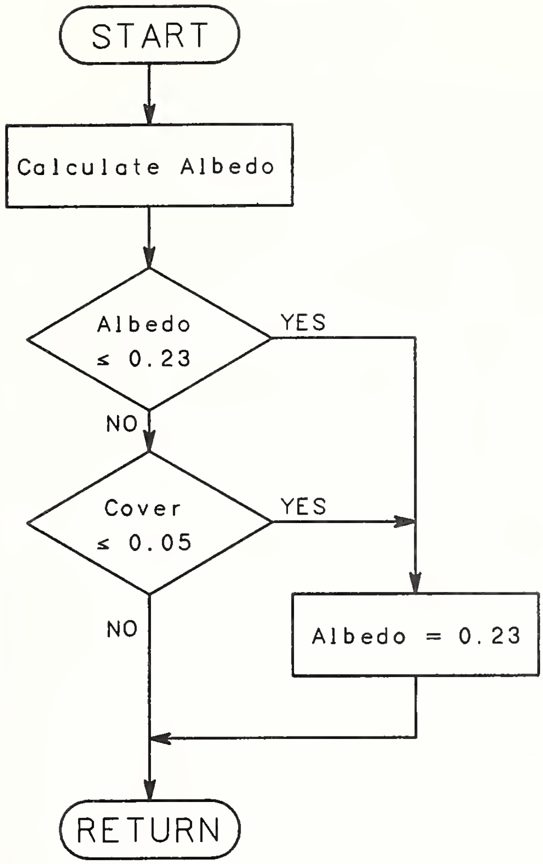


Figure 2.7
Function ALBEDO: Calculate the albedo.

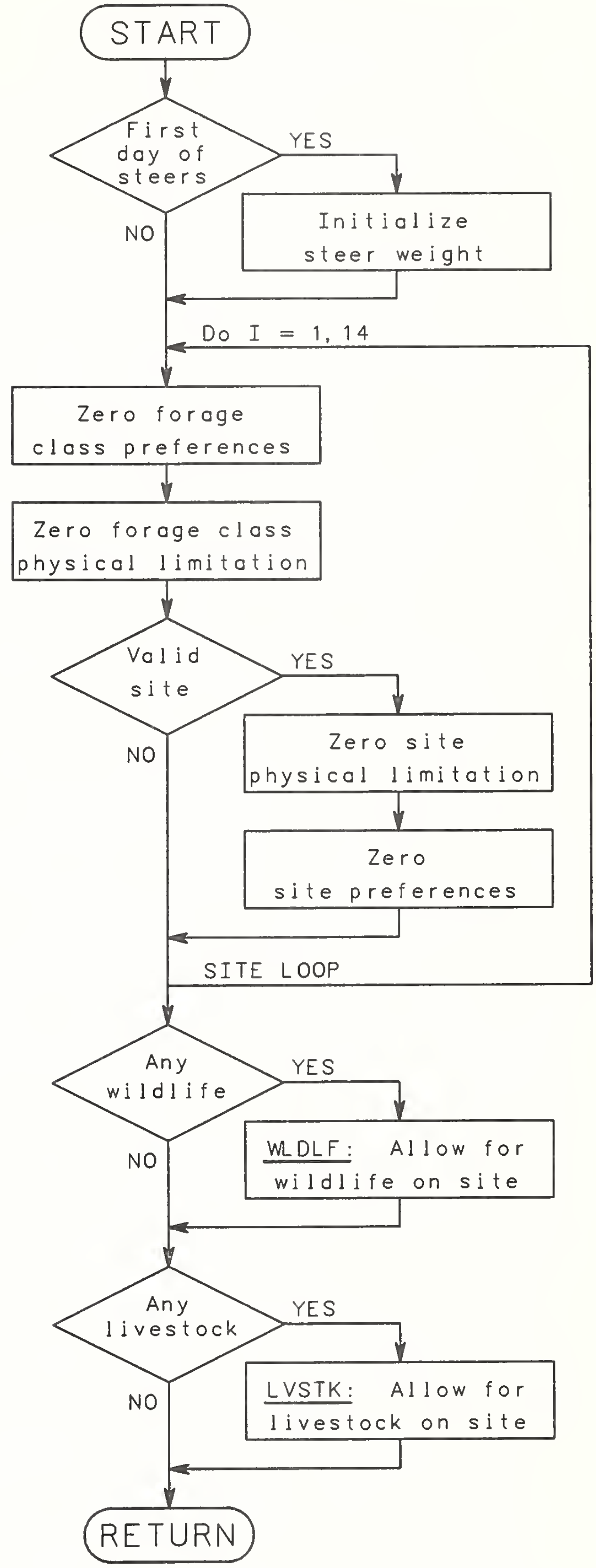


Figure 2.8
Subroutine ANIMAL: Controls calls to wildlife and livestock routines.

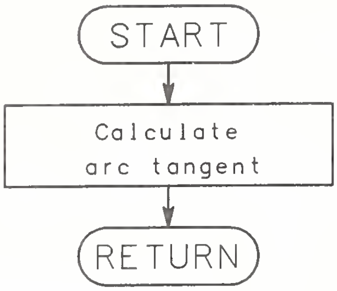


Figure 2.9
Function ATANF:
Calculate arc tangent.

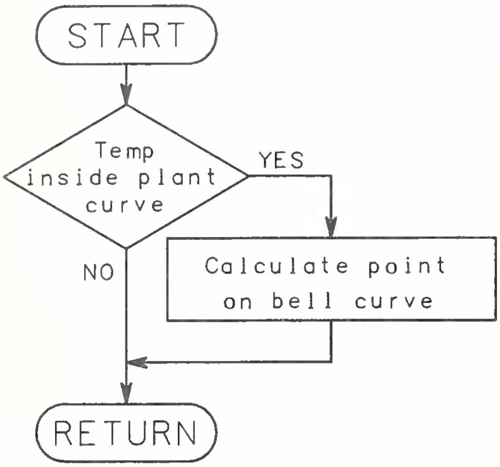


Figure 2.10
Function BELL: Calculate position on the plant bell curve.

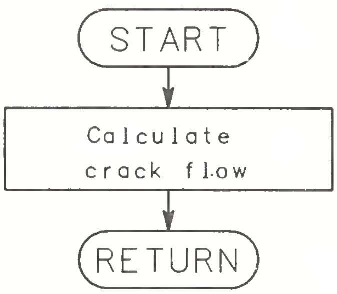


Figure 2.11
Subroutine CRACK:
Calculate water flow
through cracks.

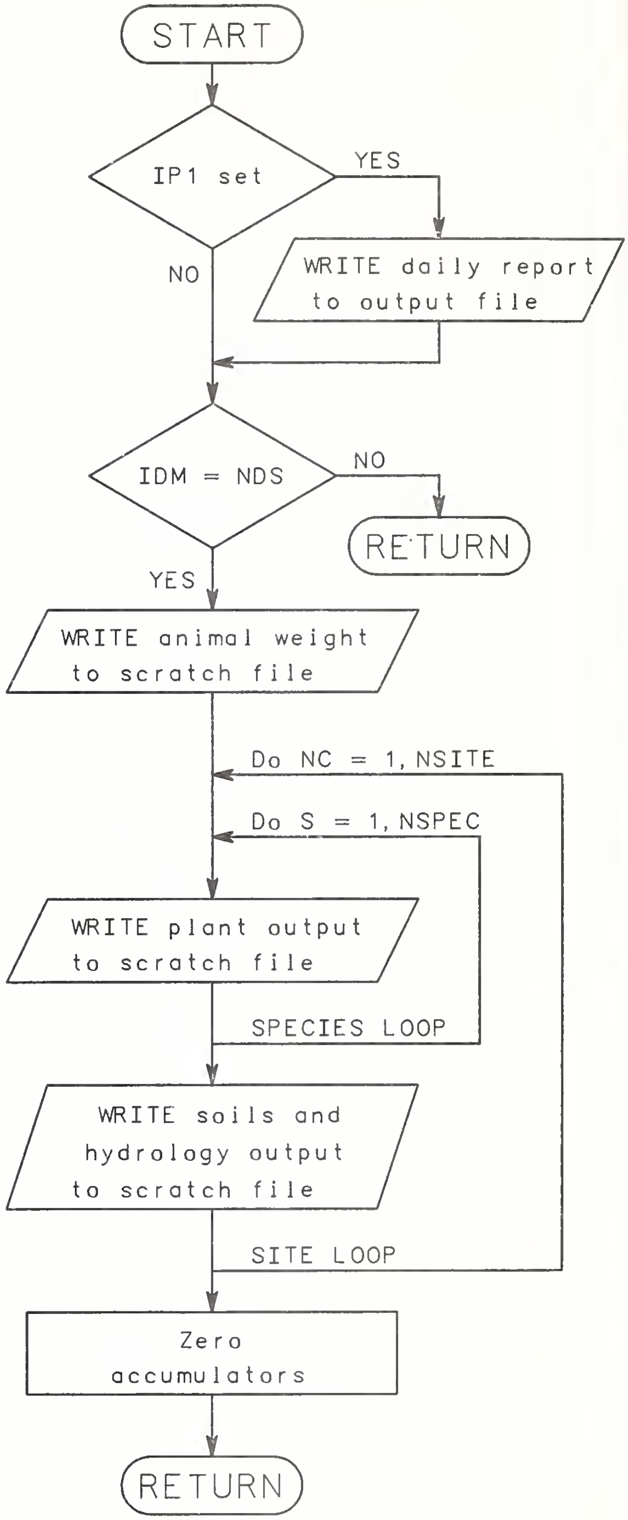


Figure 2.12
Subroutine DAYREP: Produce daily report.

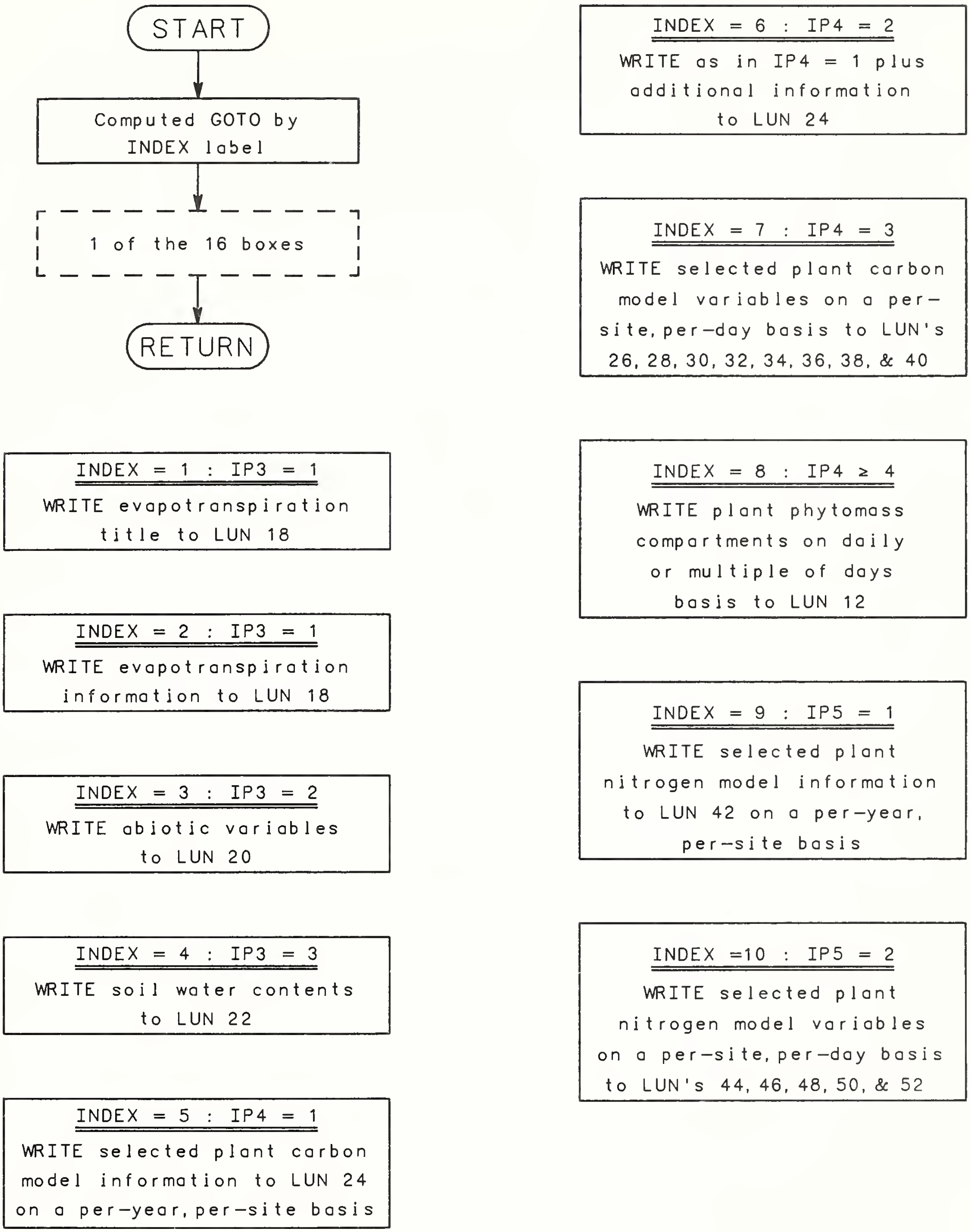


Figure 2.13
Subroutine DETAIL: Consolidated print subroutine.

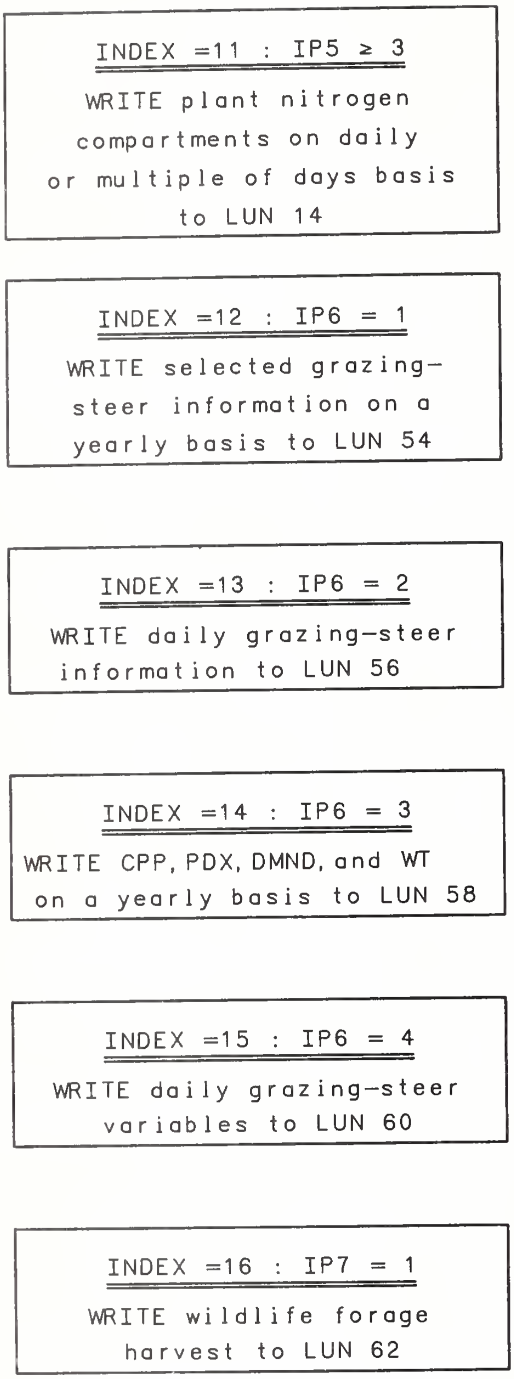


Figure 2.13--Continued
Subroutine DETAIL:
Consolidated print subroutine.

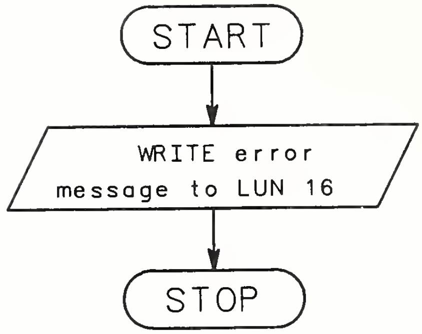


Figure 2.14
Subroutine ERR:
Generate error message.

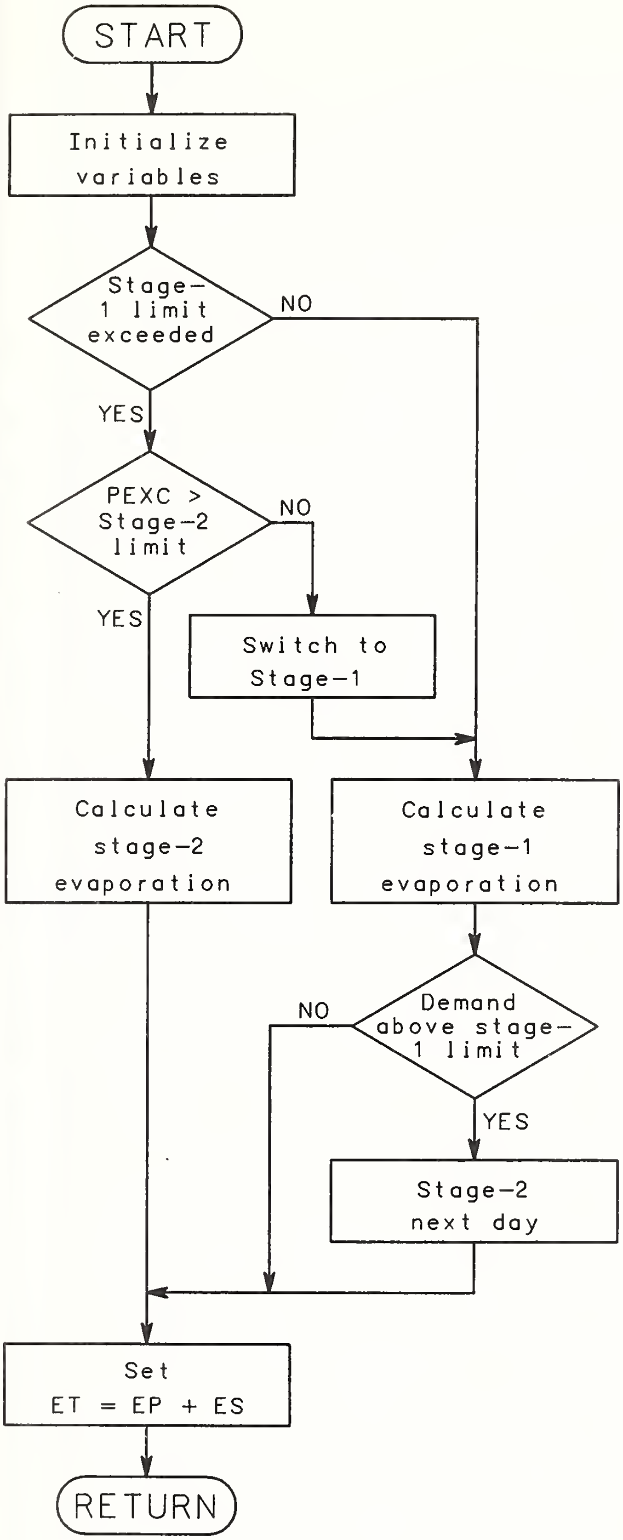


Figure 2.15
Subroutine EVAPR: Compute plant and soil evaporation.

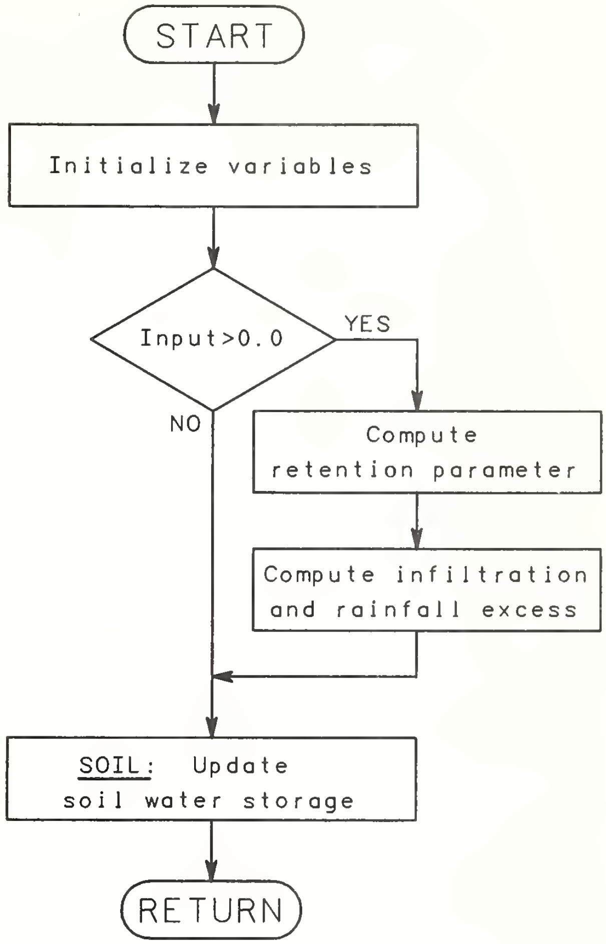


Figure 2.16
Subroutine FLDHYD: Compute surface runoff and peak runoff rate.

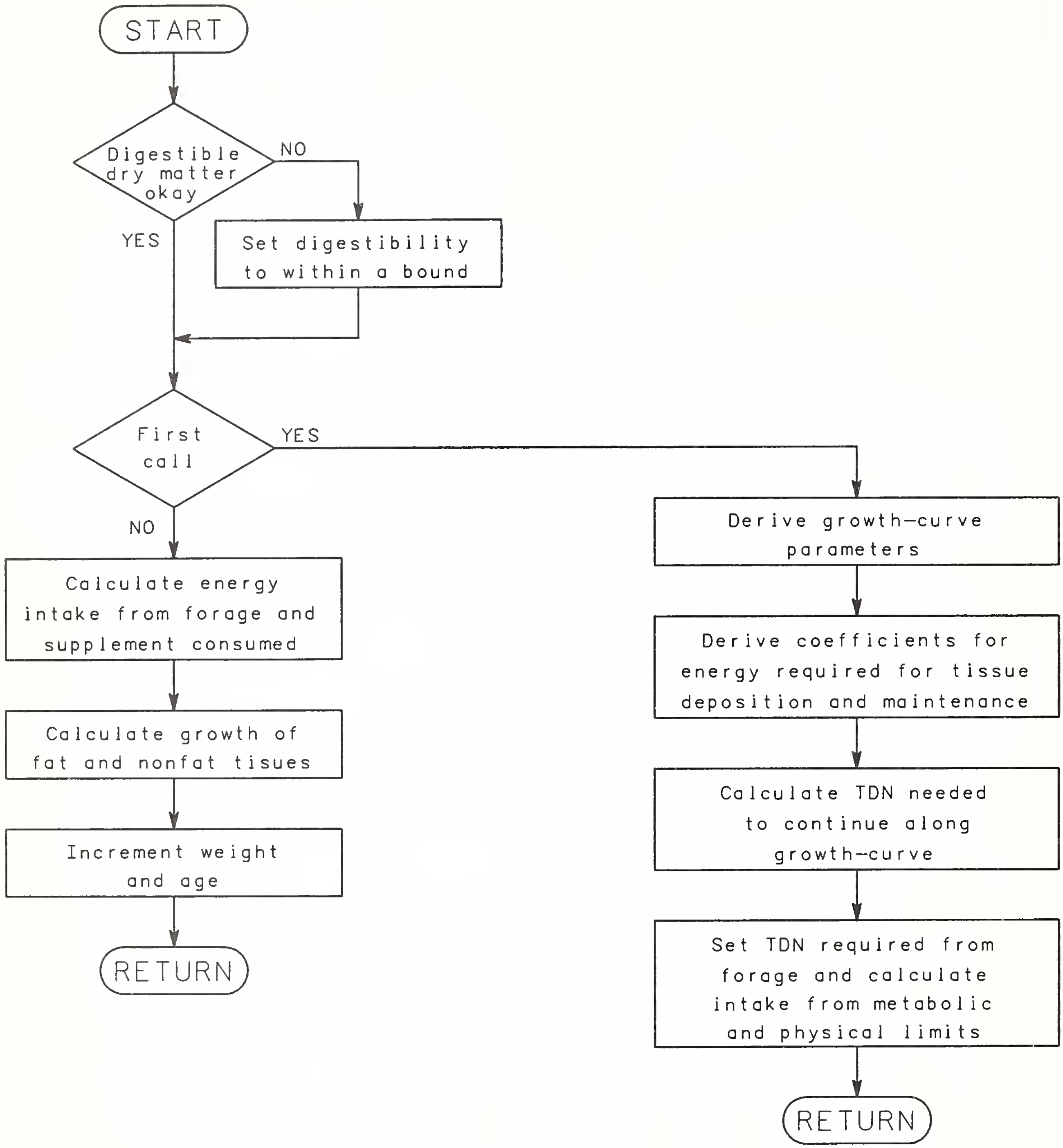


Figure 2.17
Subroutine GROW: Growth of a steer.

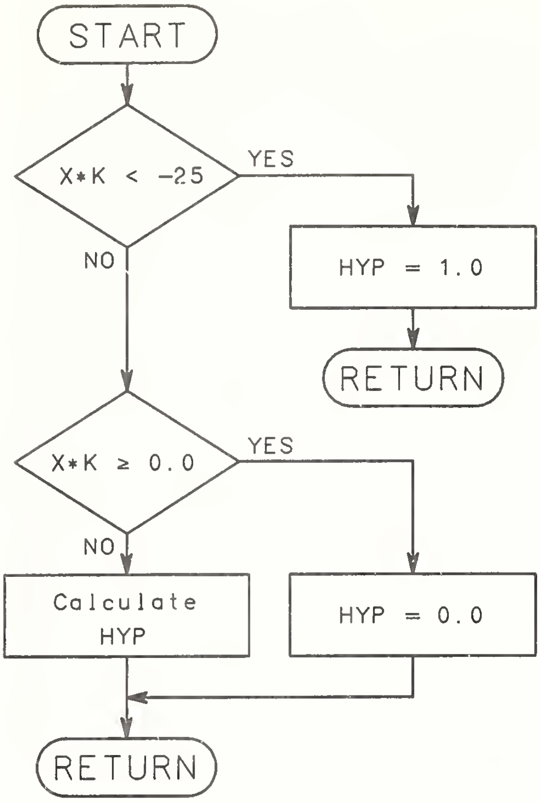


Figure 2.18
Function HYP: Hyperbolic function.

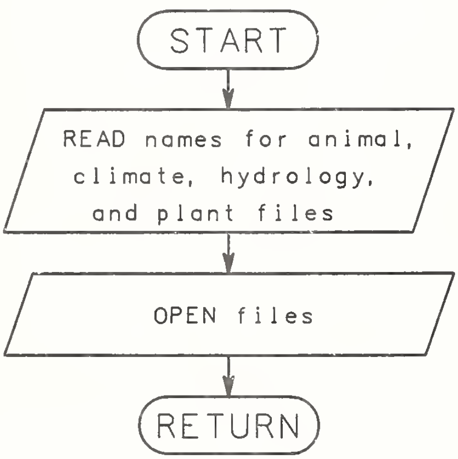


Figure 2.19
Subroutine IOSET: Link input files.

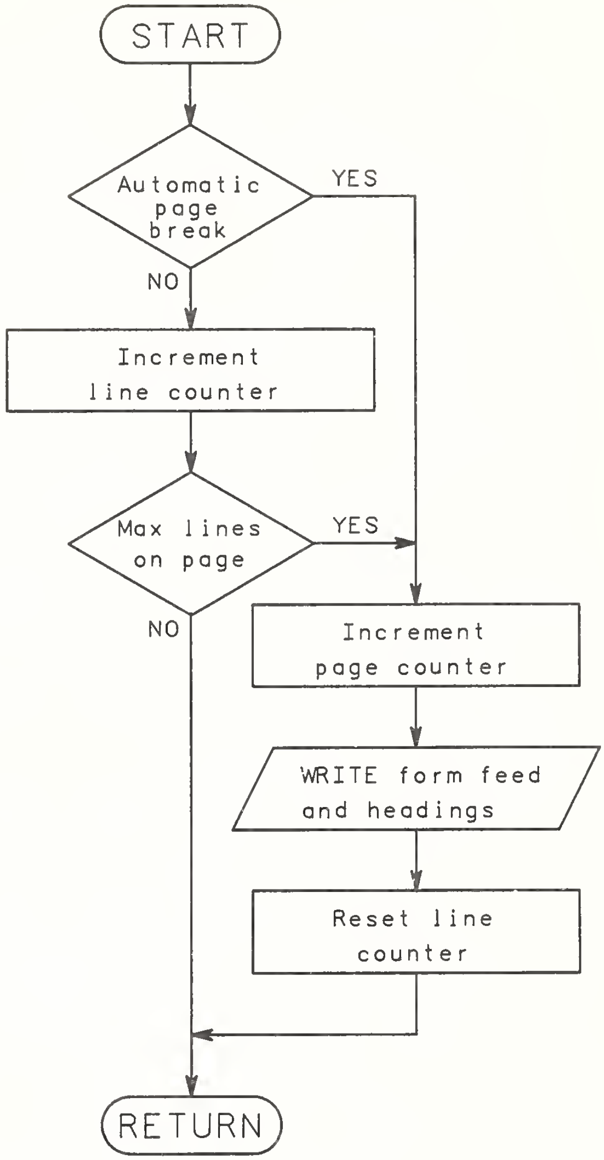


Figure 2.20
Subroutine LINE: Generate form feeds in ouput file.

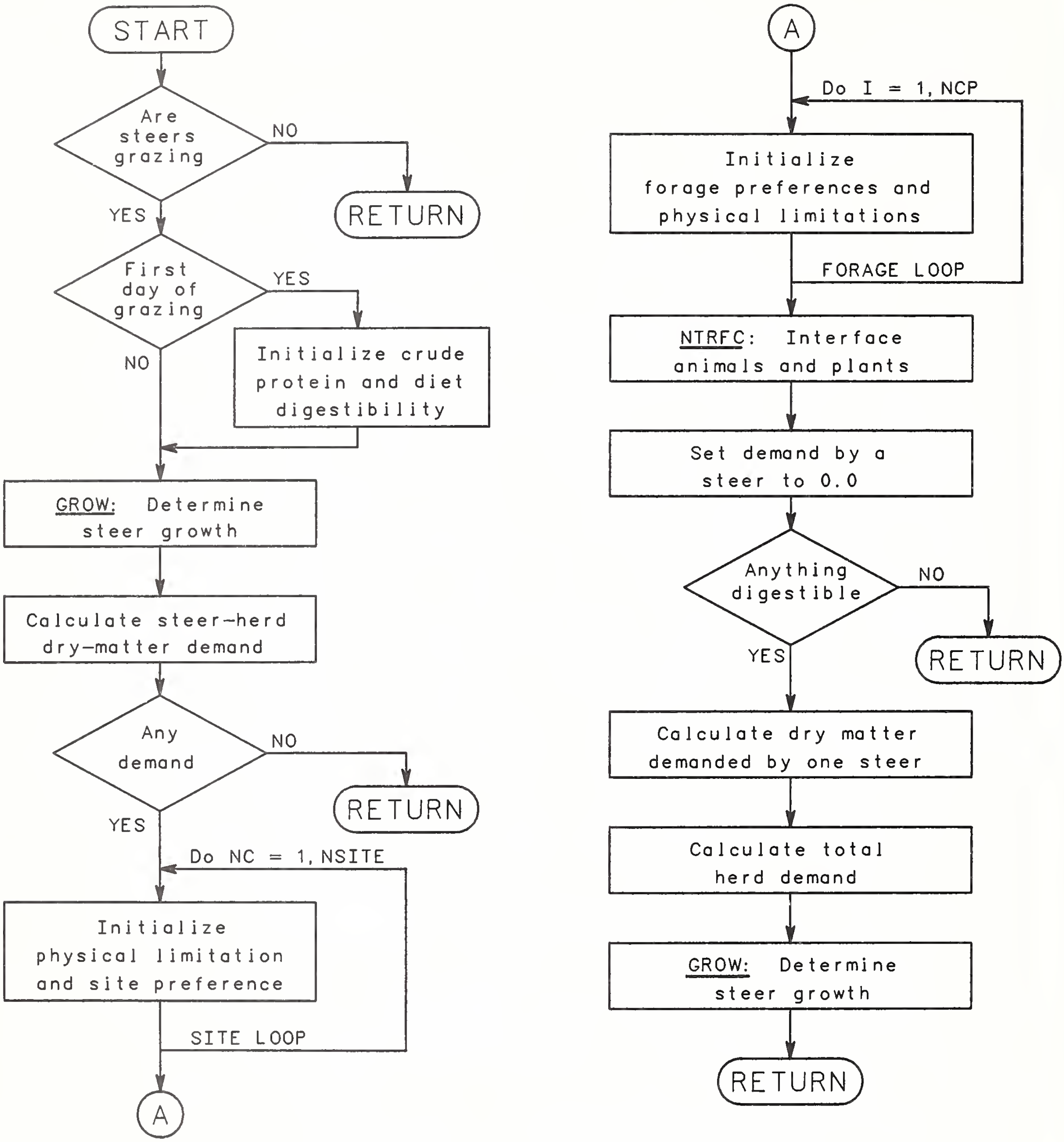


Figure 2.21
Subroutine LVSTK: Allow for livestock usage.

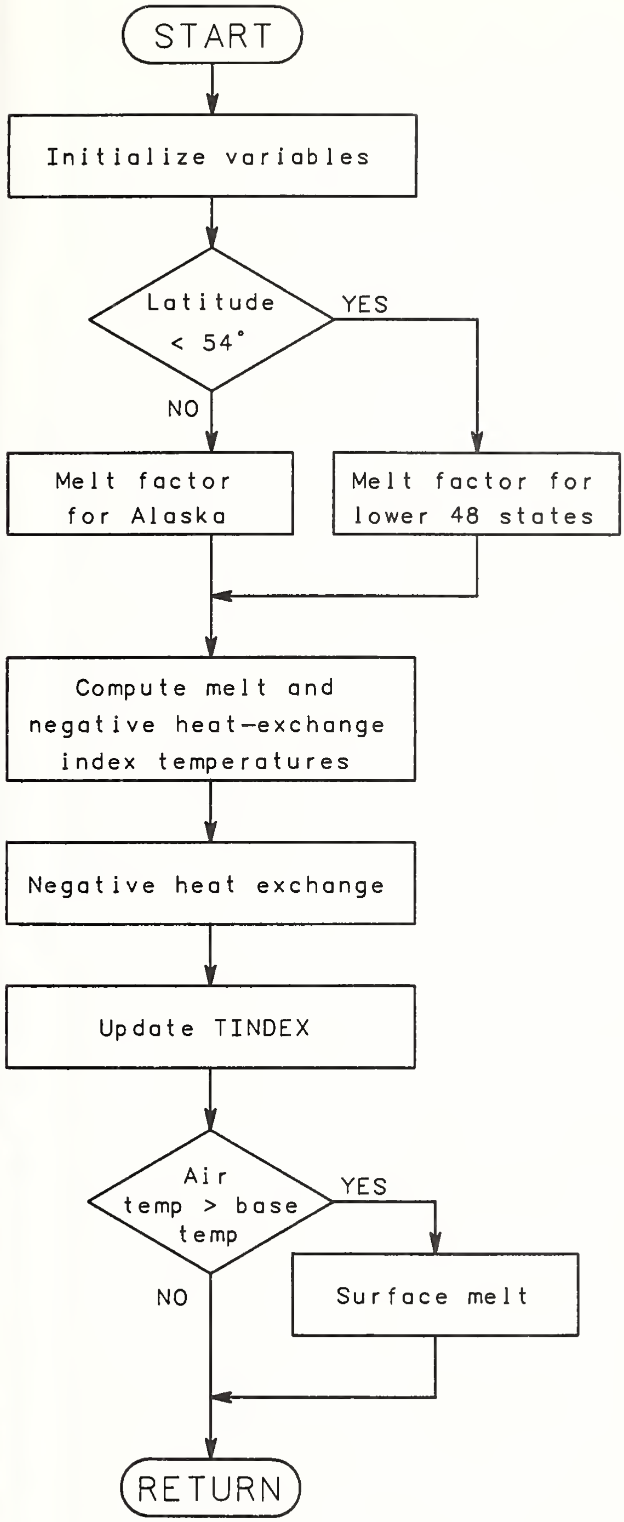


Figure 2.22
Subroutine MELT19: Compute surface melt.

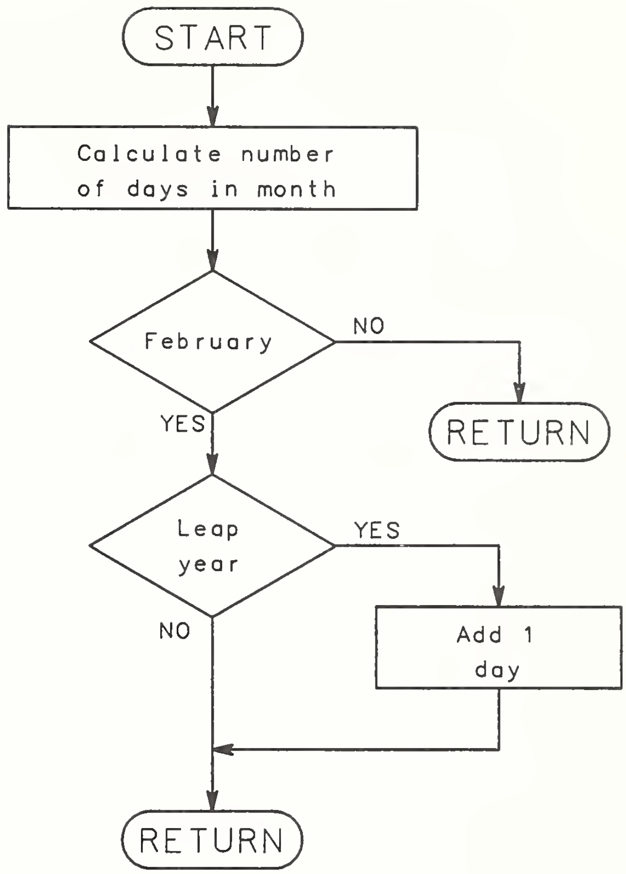


Figure 2.23
Subroutine NDPM: Calculate number of days in the month.

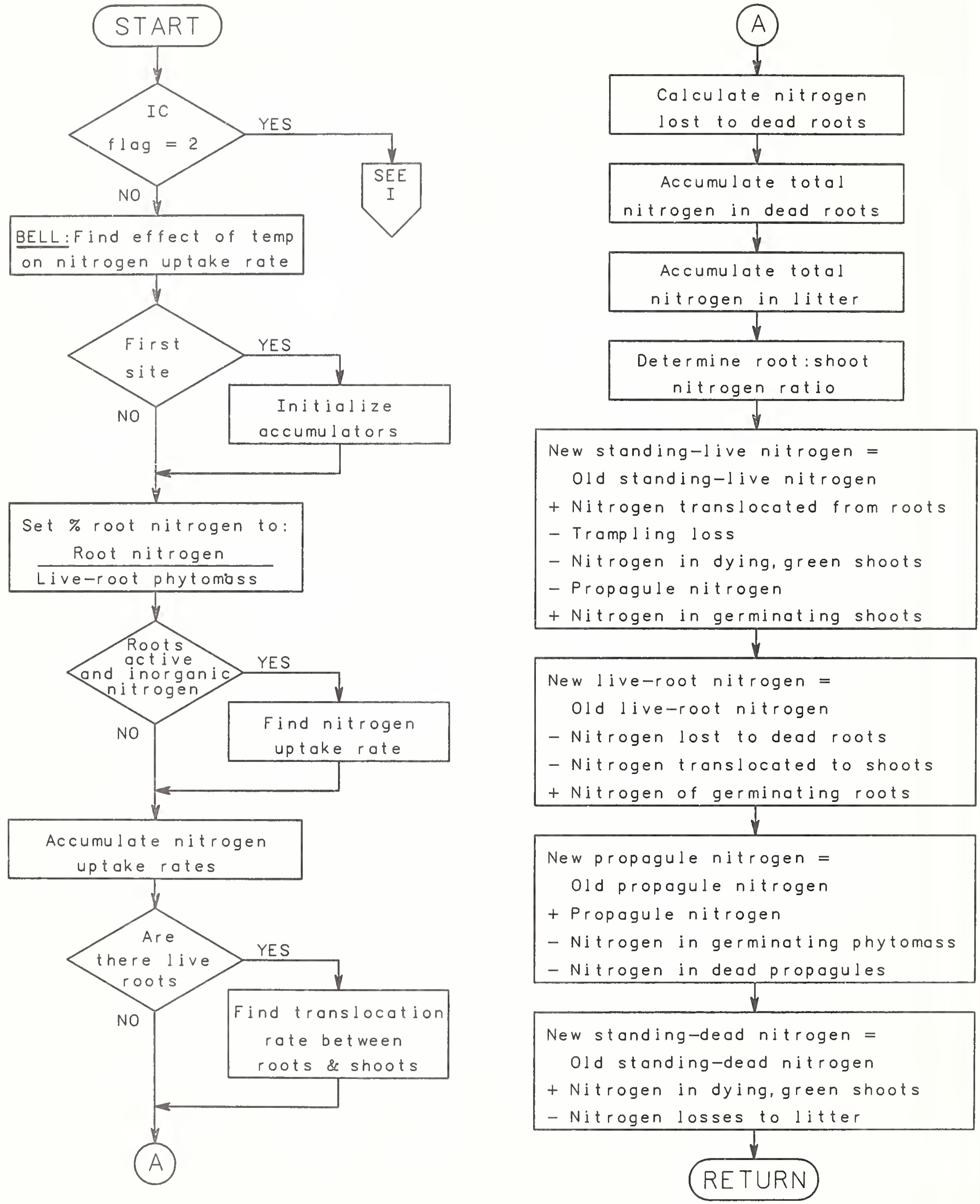


Figure 2.24
Subroutine NITE: Plant species nitrogen model.

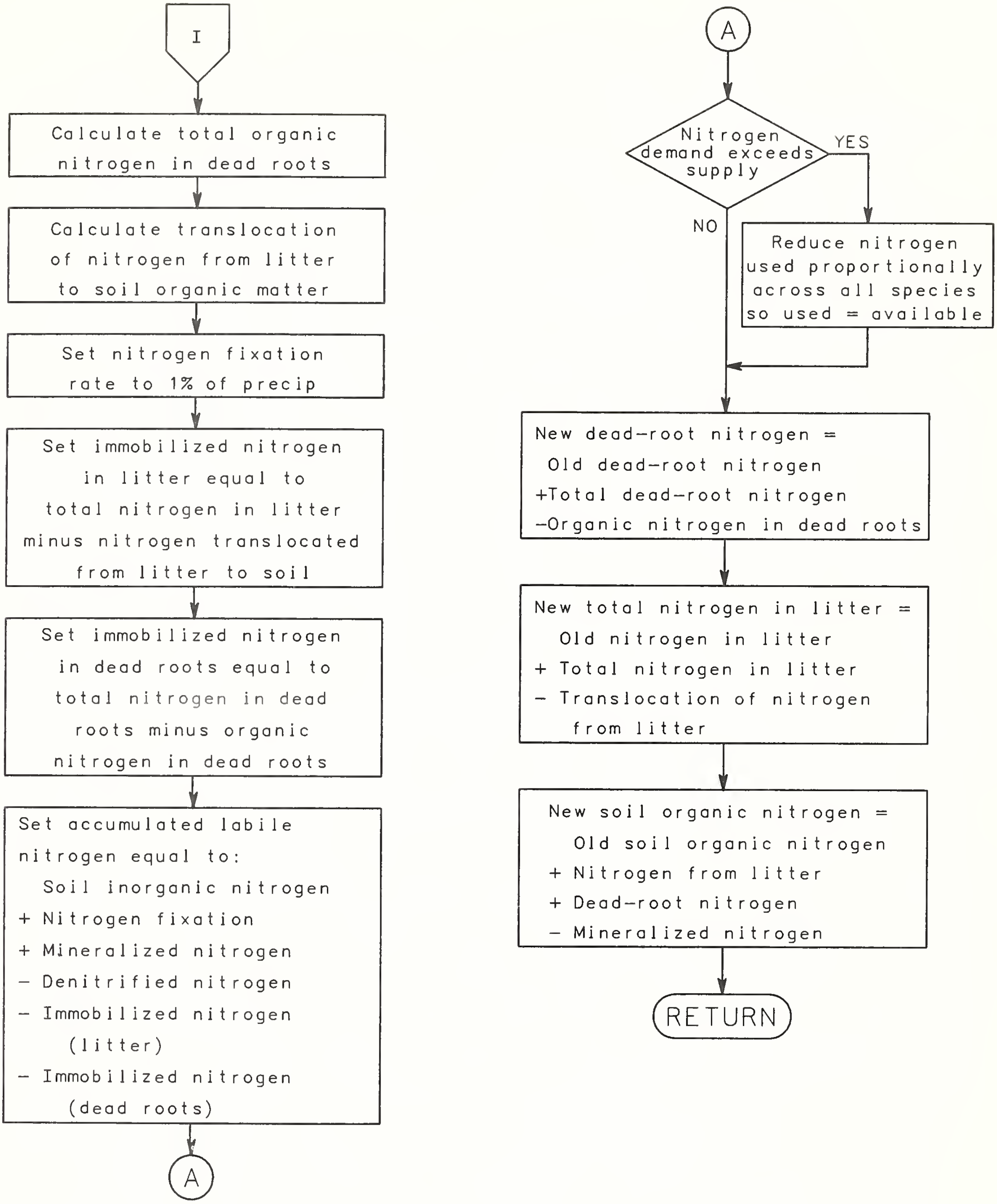


Figure 2.24--Continued
Subroutine NITE: Plant species nitrogen model.

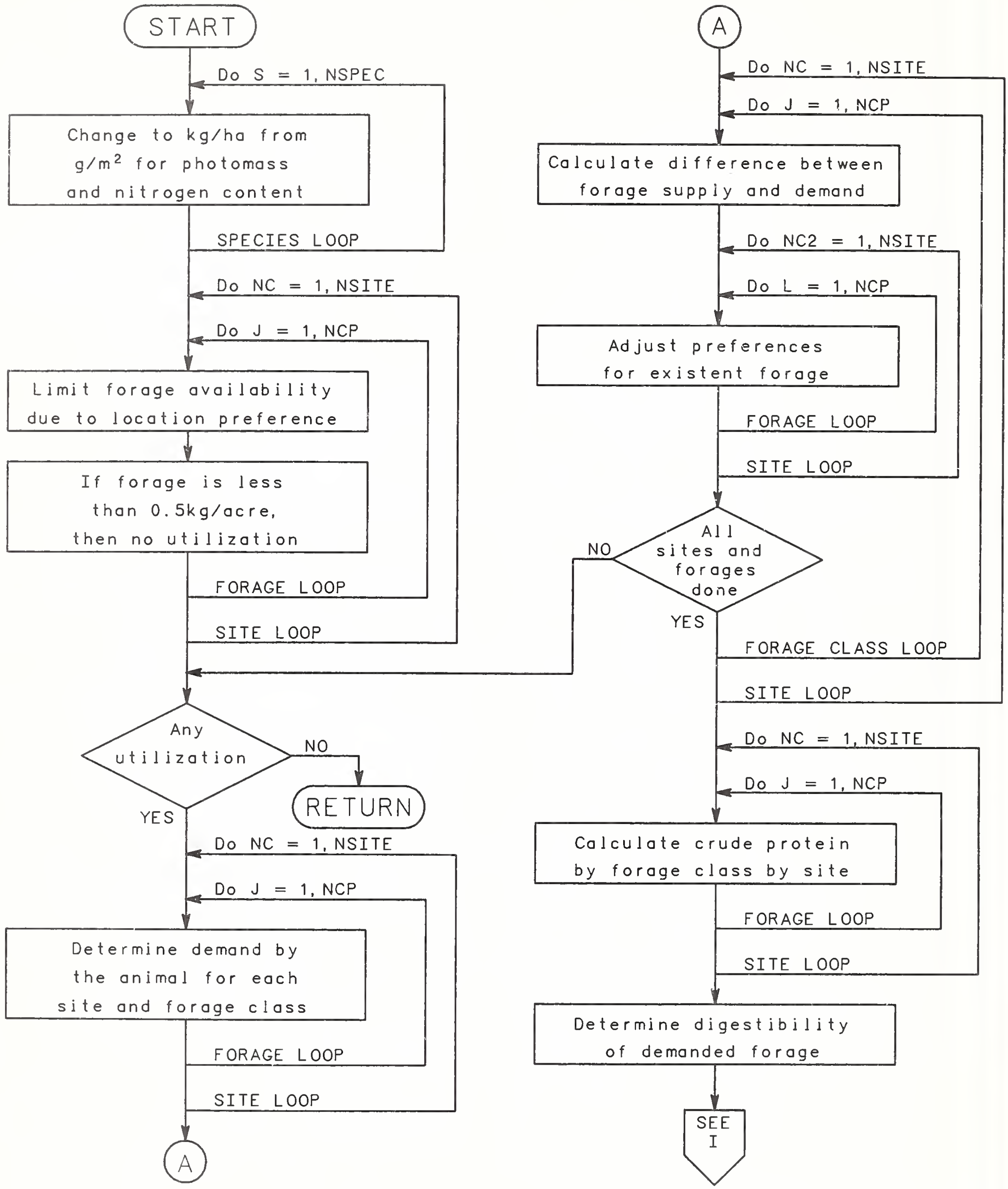


Figure 2.25
Subroutine NTRFC: Interface of animal and plant components.

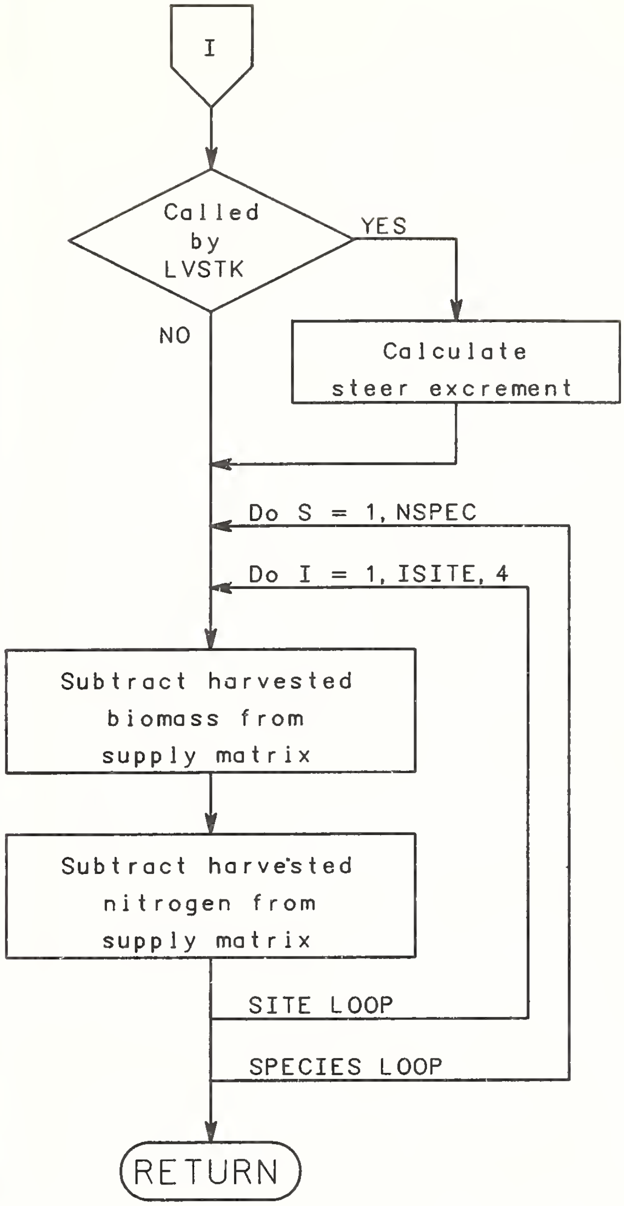


Figure 2.25--Continued
Subroutine NTRFC: Interface of
animal and plant components.

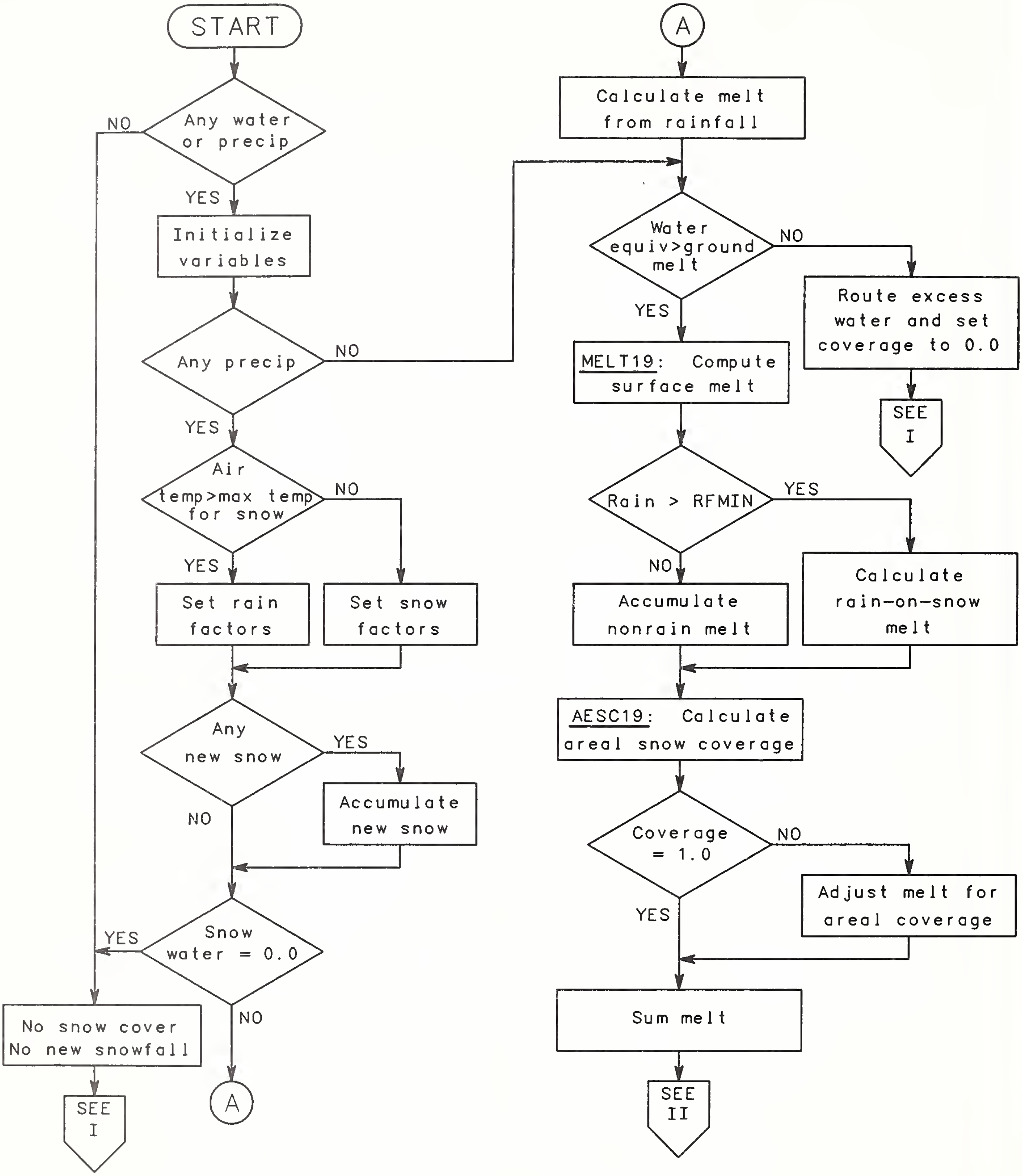


Figure 2.26
Subroutine PACK19: Snow accumulation and melt routine.

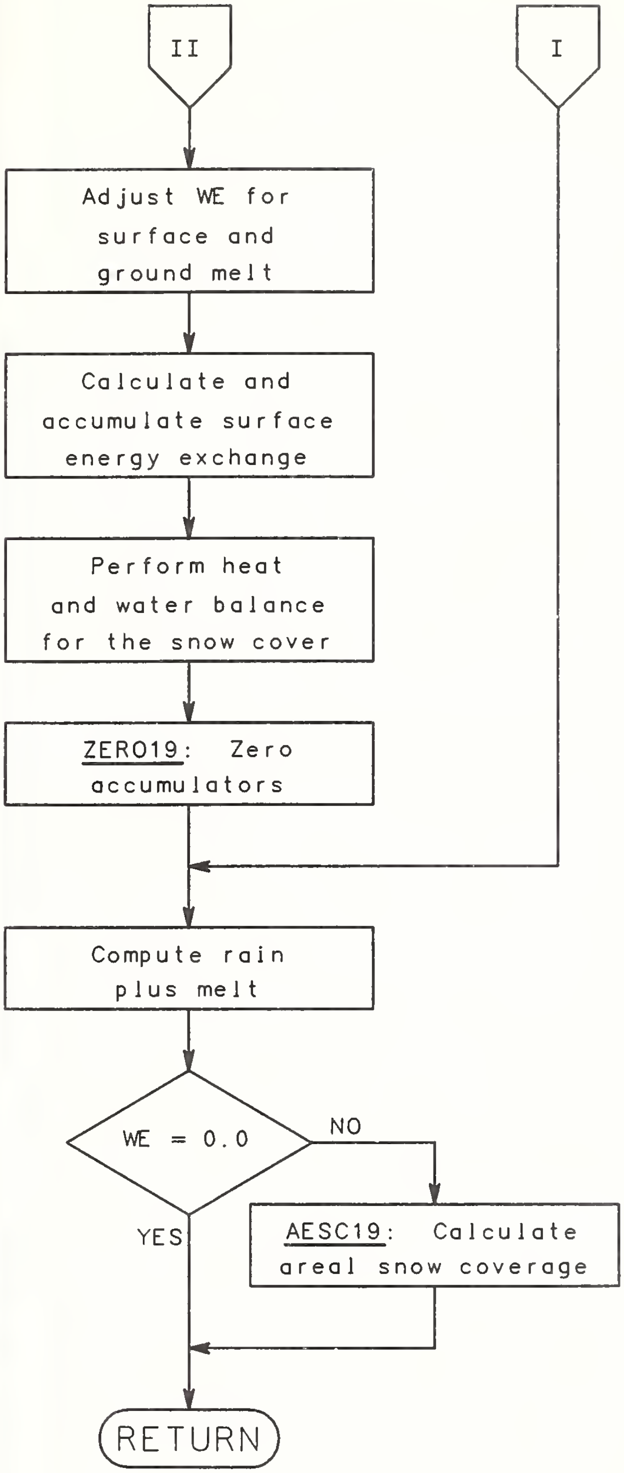


Figure 2.26--Continued
Subroutine PACK19: Snow accumulation and melt routine.

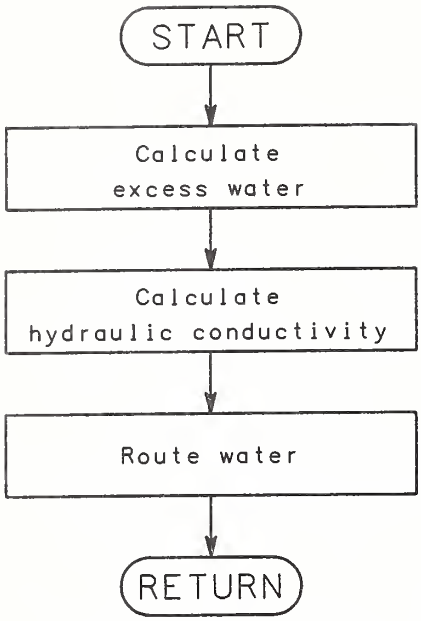


Figure 2.27
Subroutine PERC:
Percolate water through
soil layers.

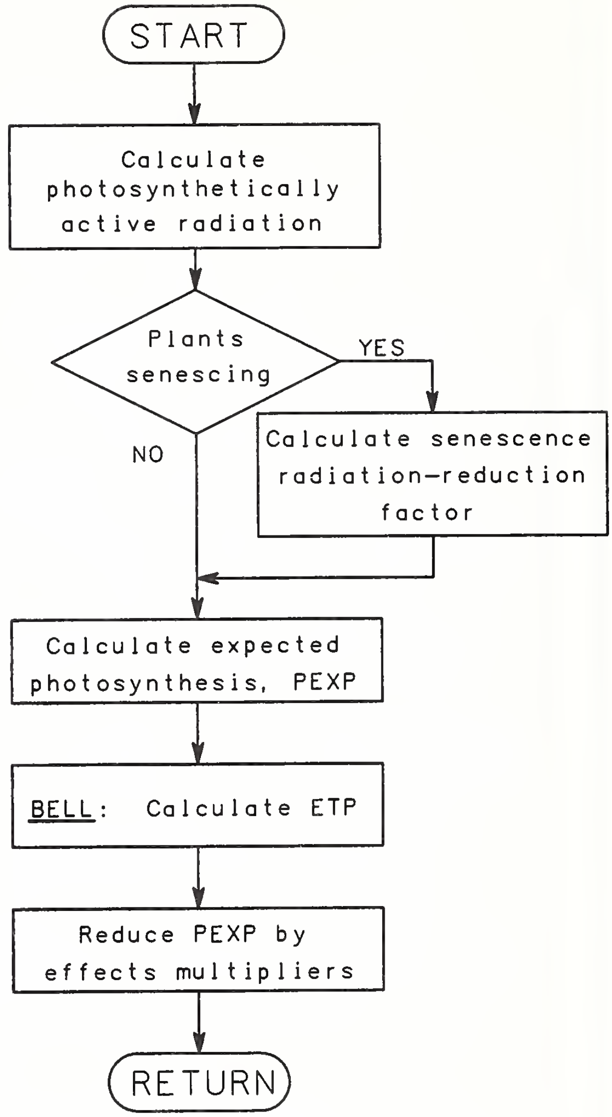


Figure 2.28
Function PEXP:
Calculate expected
photosynthesis.

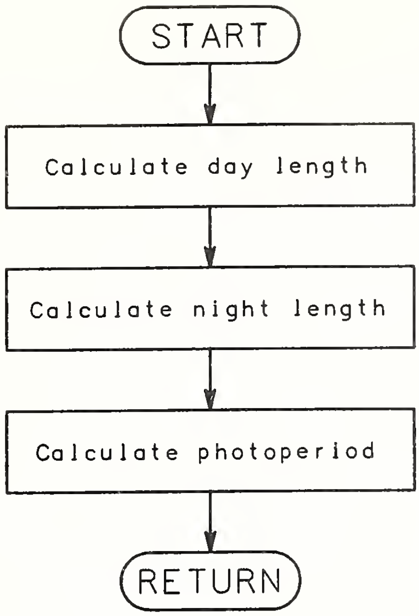


Figure 2.29
Function PHOPER:
Calculate photoperiod.

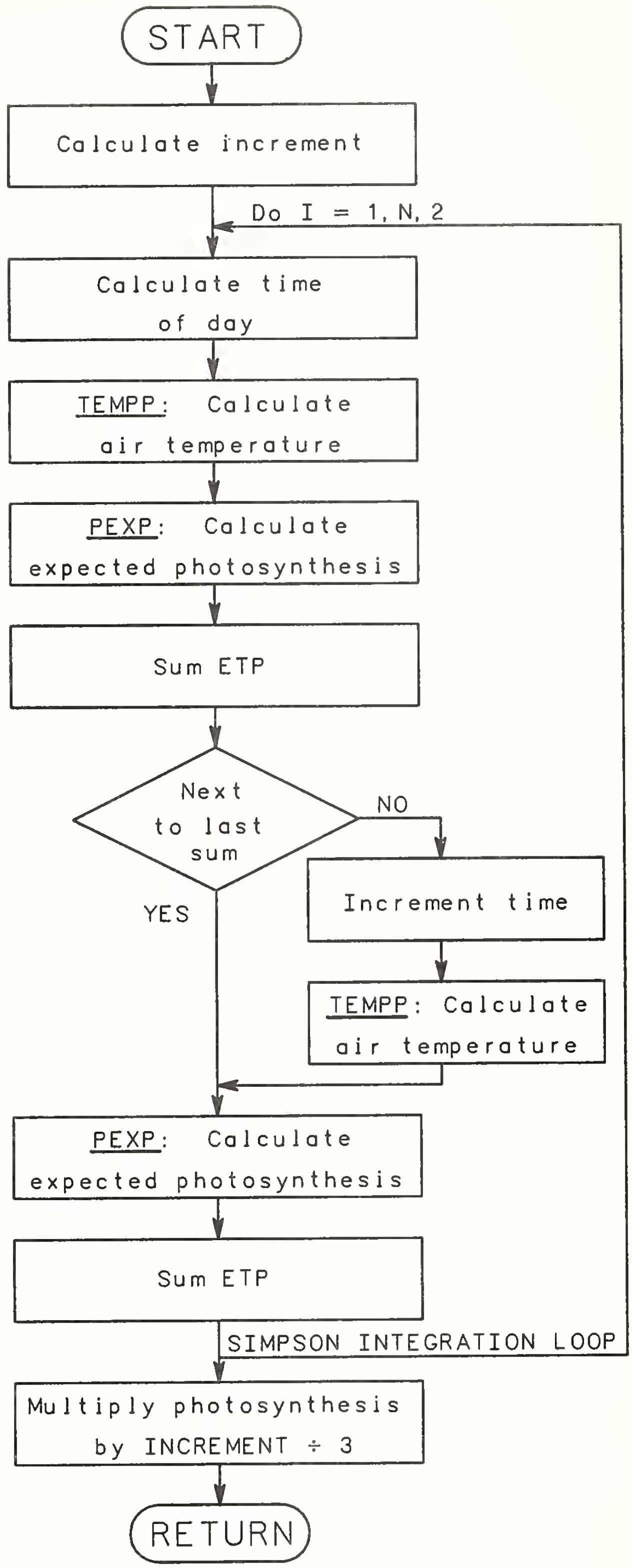


Figure 2.30
Subroutine PHOTO:
Numerically integrate
daily photosynthesis.

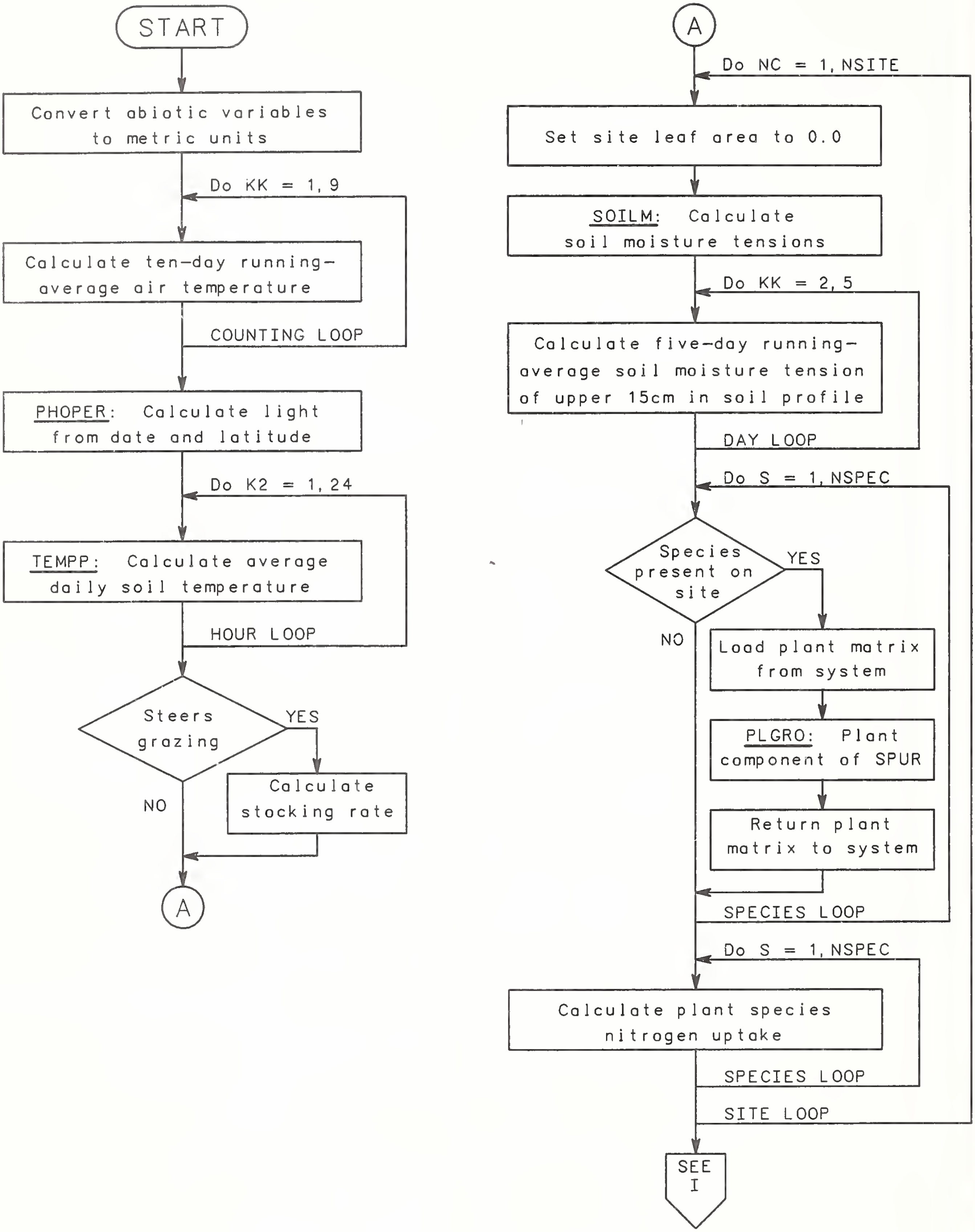


Figure 2.31
Subroutine PLANT: Plant component.

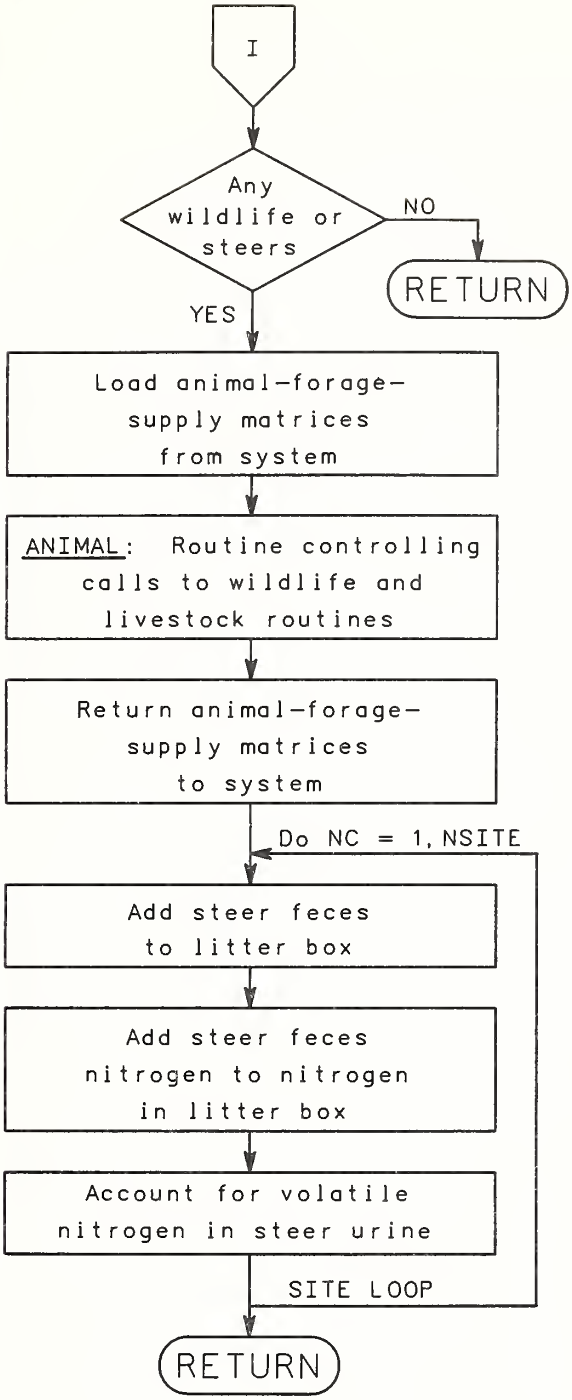


Figure 2.31--Continued
Subroutine PLANT:
Plant component.

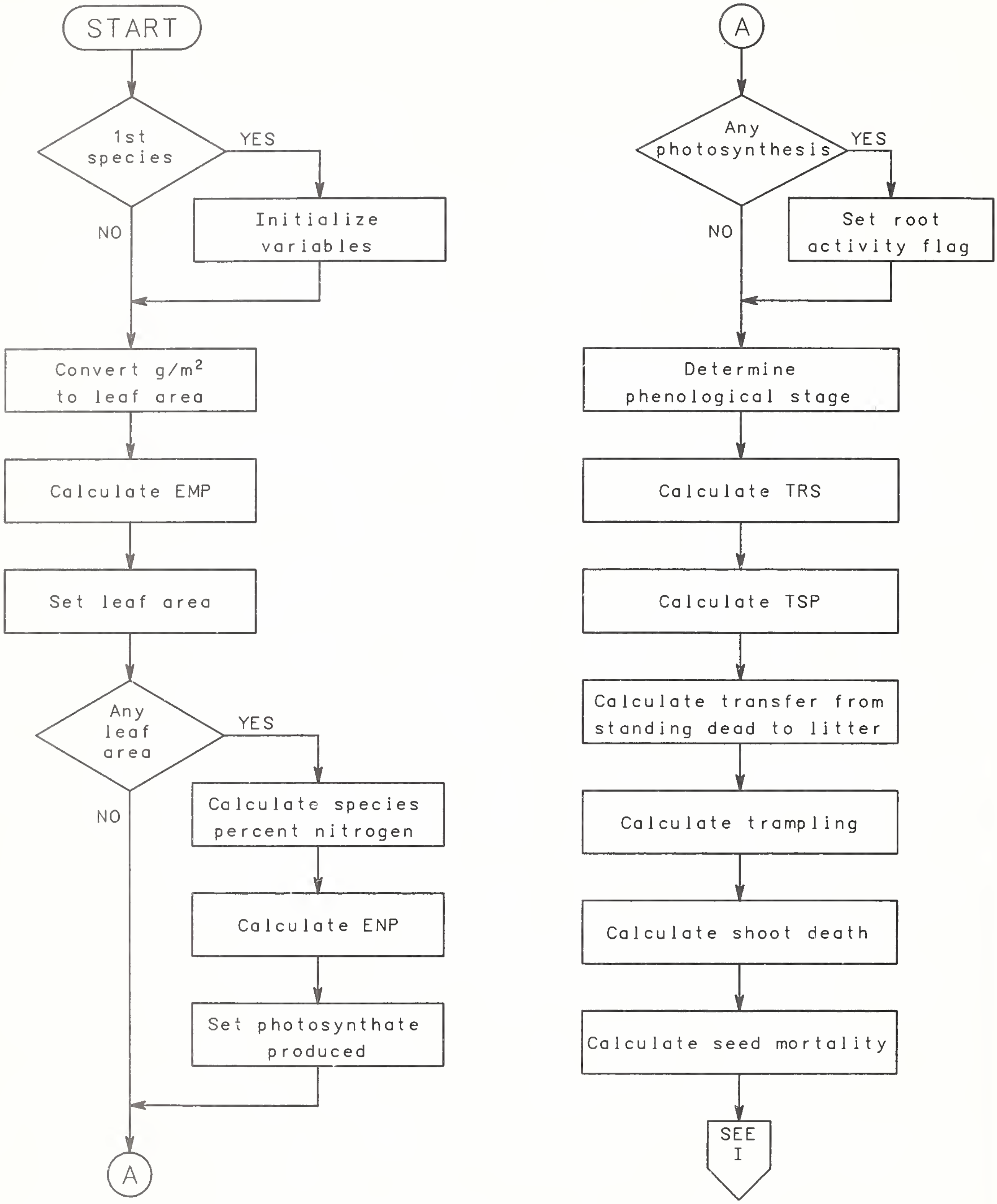


Figure 2.32
Subroutine PLGRO: Growth of plants.

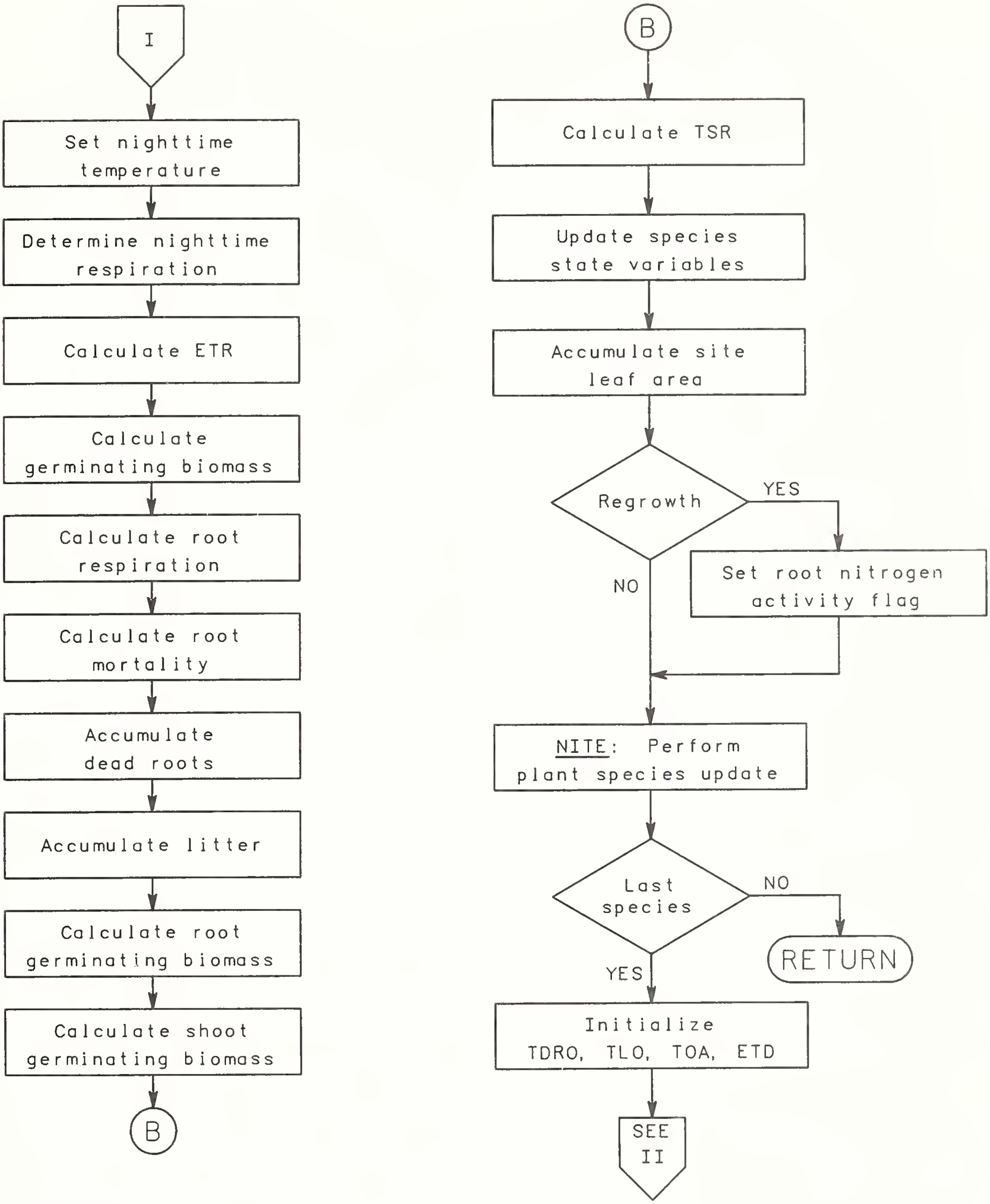


Figure 2.32--Continued
Subroutine PLGRO: Growth of plants.

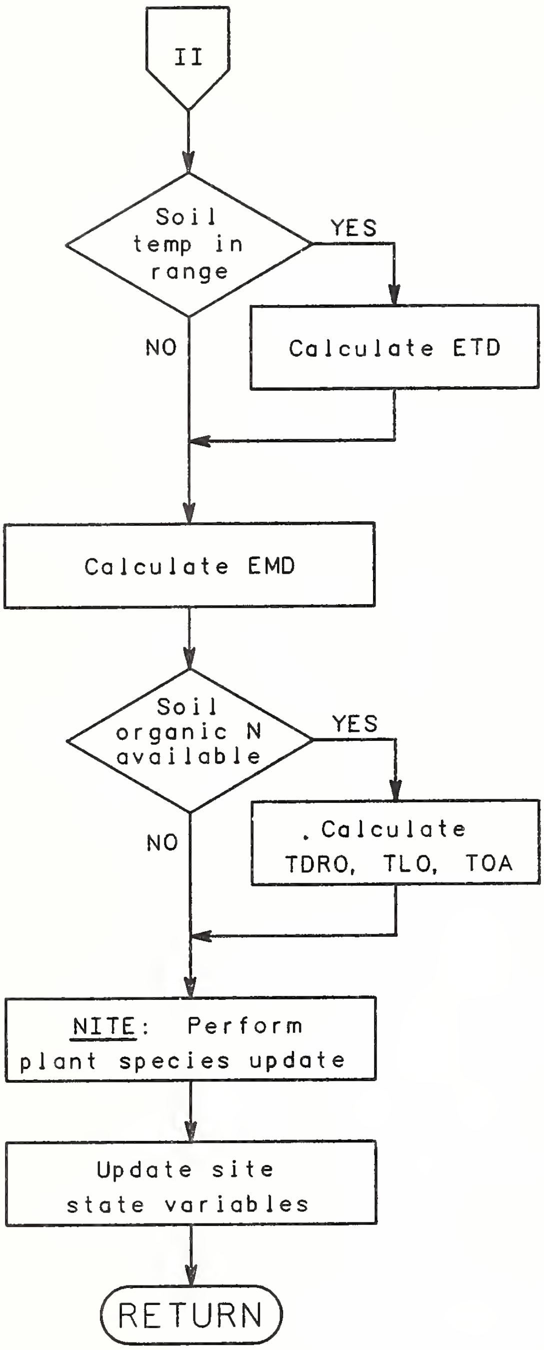


Figure 2.32--Continued
Subroutine PLGRO:
Growth of plants.

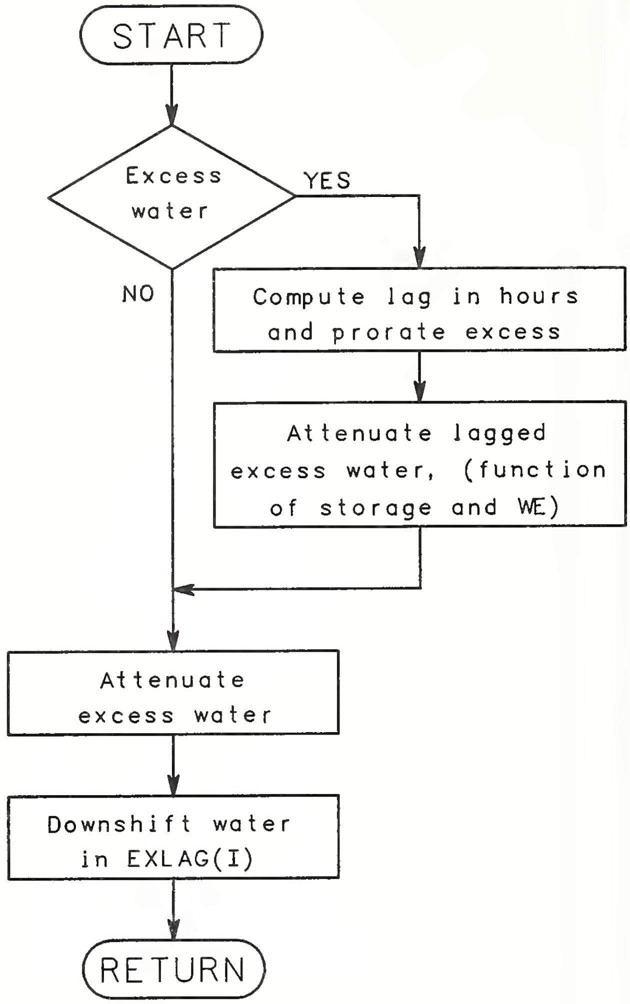


Figure 2.33
Subroutine ROUT19:
Route excess water
through snow.

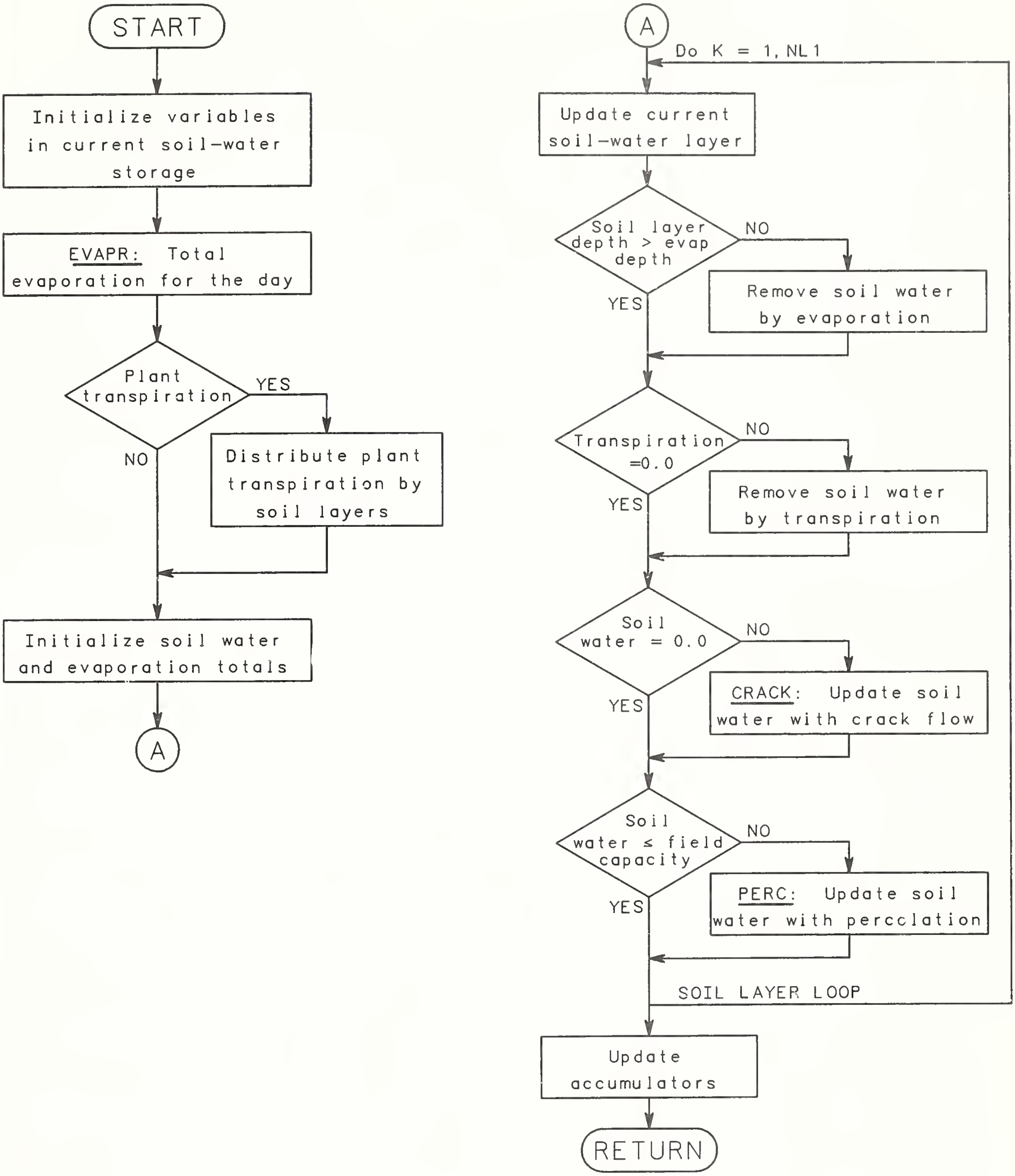


Figure 2.34
Subroutine SOIL: Update soil-water storage.

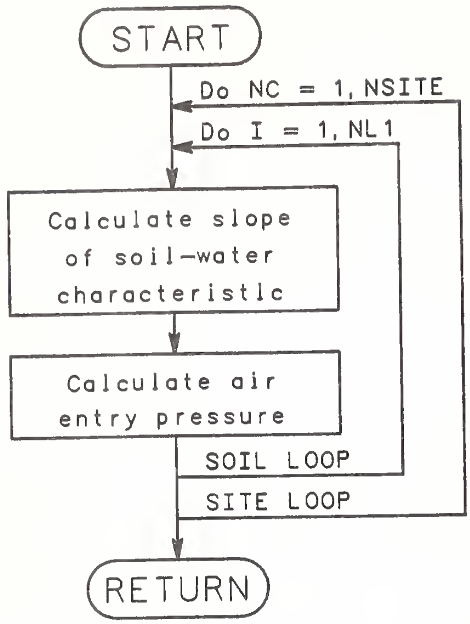


Figure 2.35
Subroutine SOILC:
Determine the moisture characteristics.

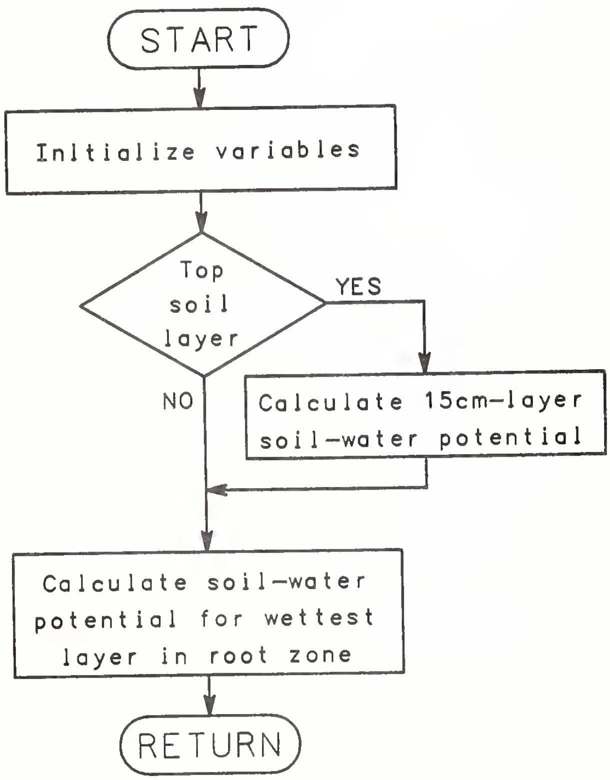


Figure 2.36
Subroutine SOILM:
Calculate soil-water potentials.

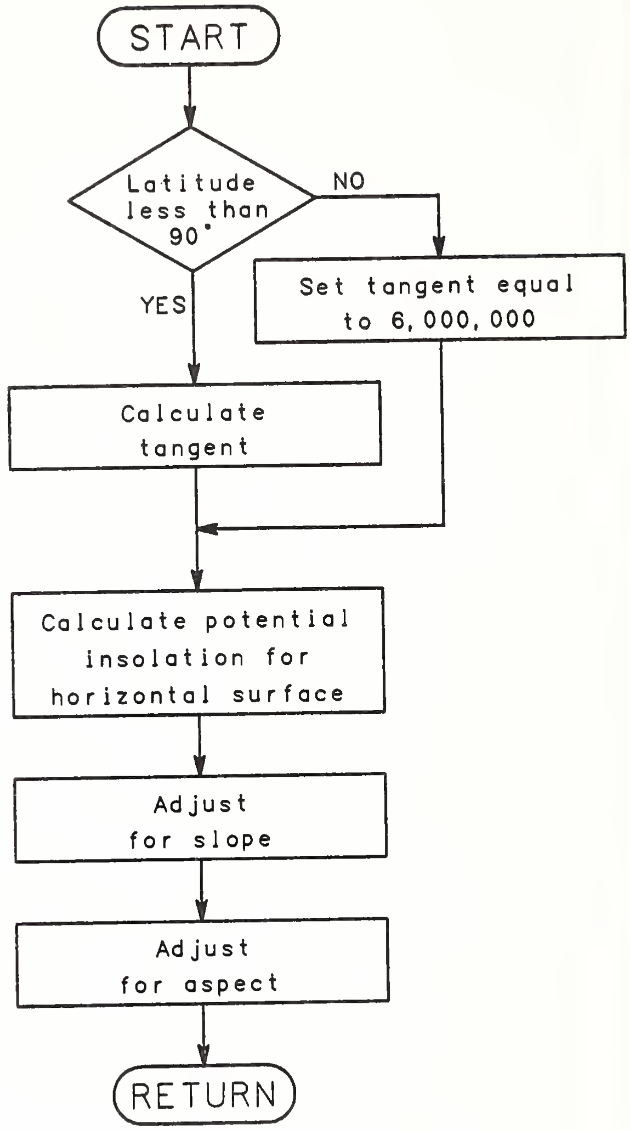


Figure 2.37
Function SOLADJ: Correct solar radiation.

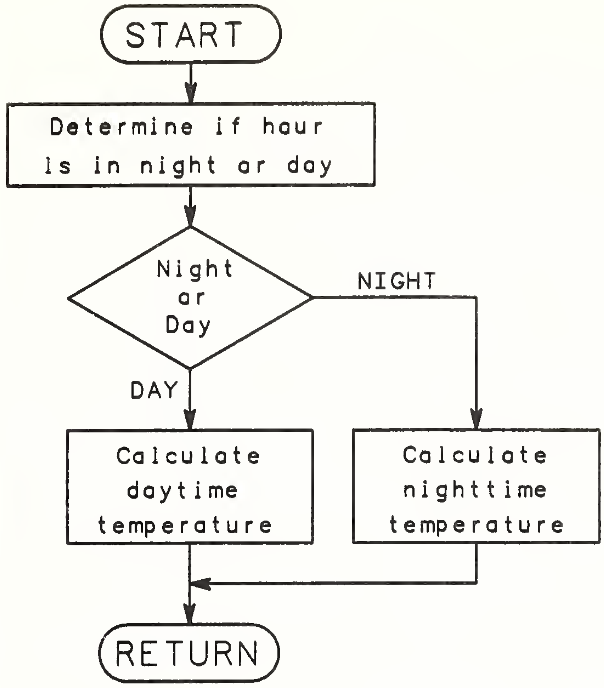


Figure 2.38
Function TEMPP: Calculate temperature.

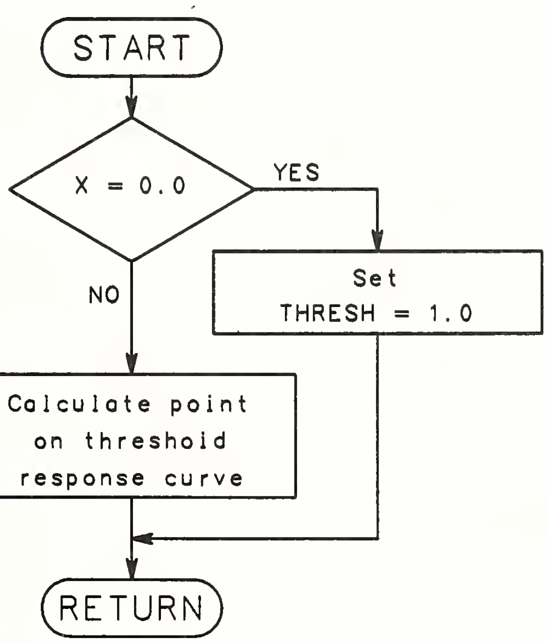


Figure 2.39
Function THRESH: Determine threshold point.

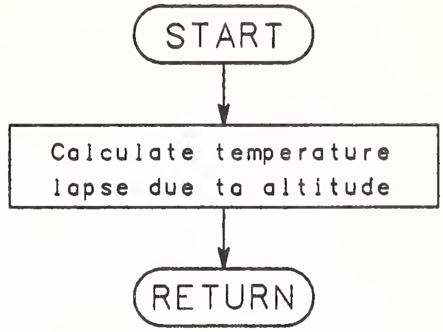


Figure 2.40
Function TLAPSE: Calculate temperature lapse due to altitude.

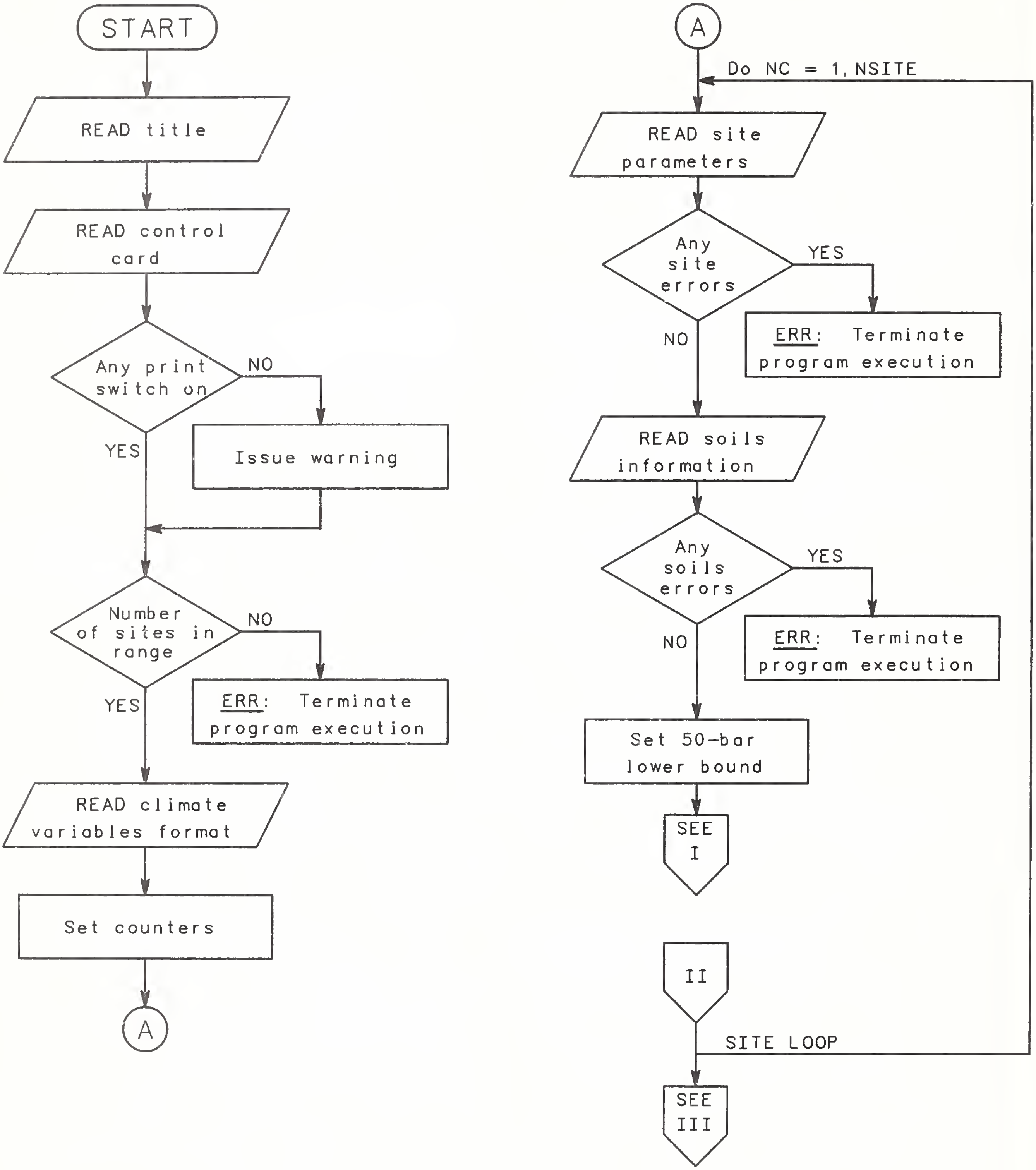


Figure 2.41
Subroutine USER: Initialization of the model.

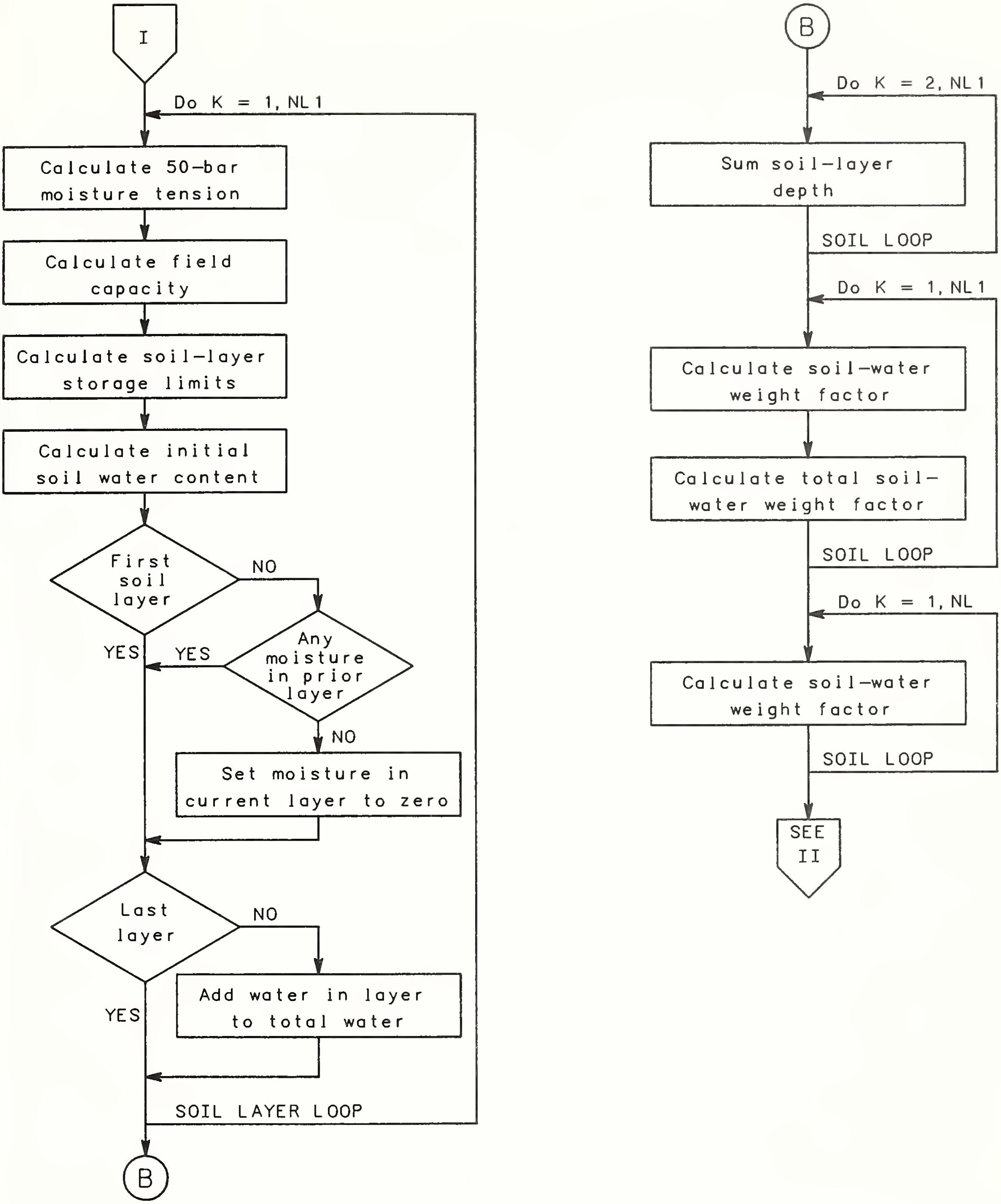


Figure 2.41--Continued
Subroutine USER: Initialization of the model.

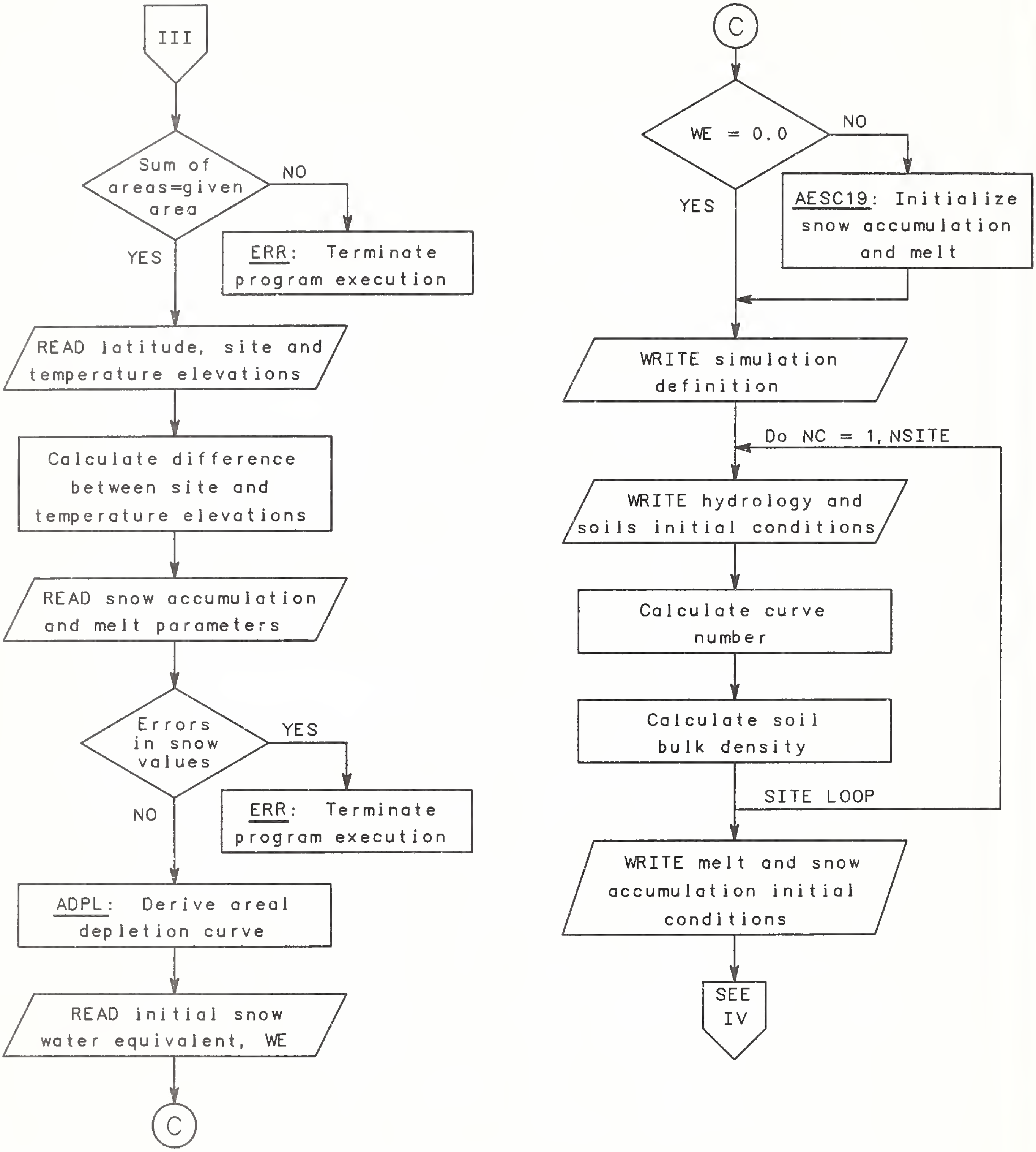


Figure 2.41--Continued
Subroutine USER: Initialization of the model.

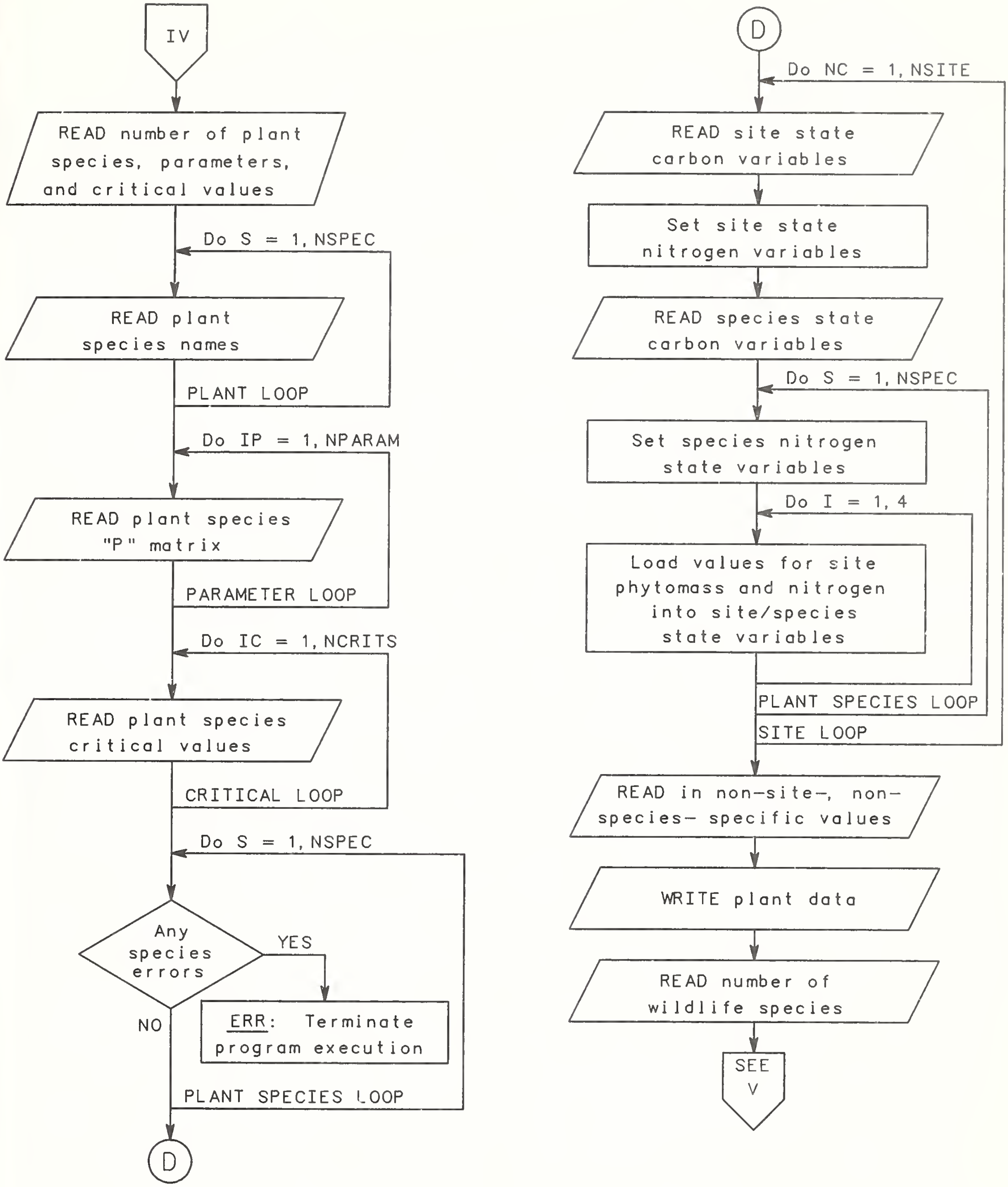


Figure 2.41--Continued
Subroutine USER: Initialization of the model.

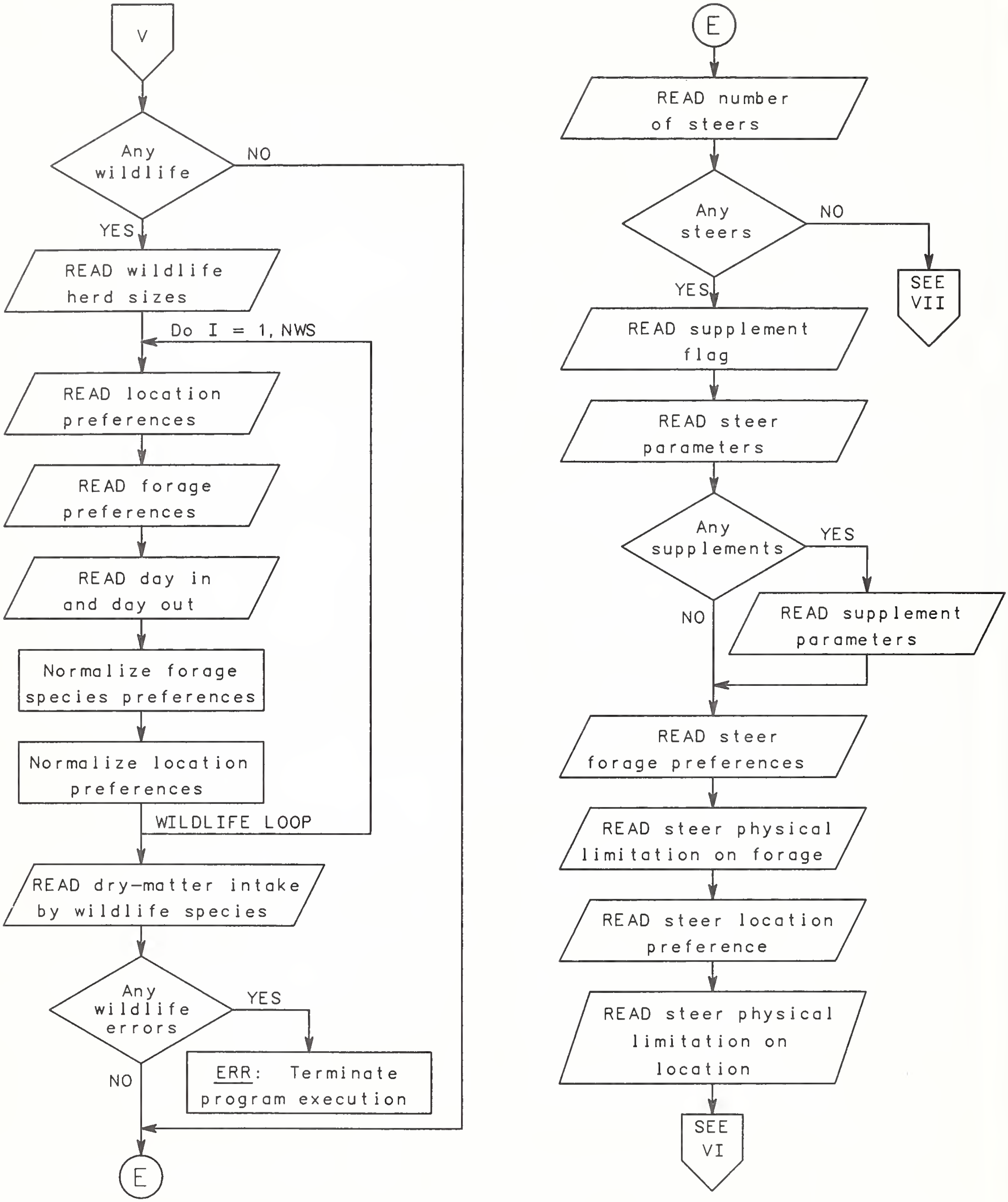


Figure 2.41--Continued
Subroutine USER: Initialization of the model.

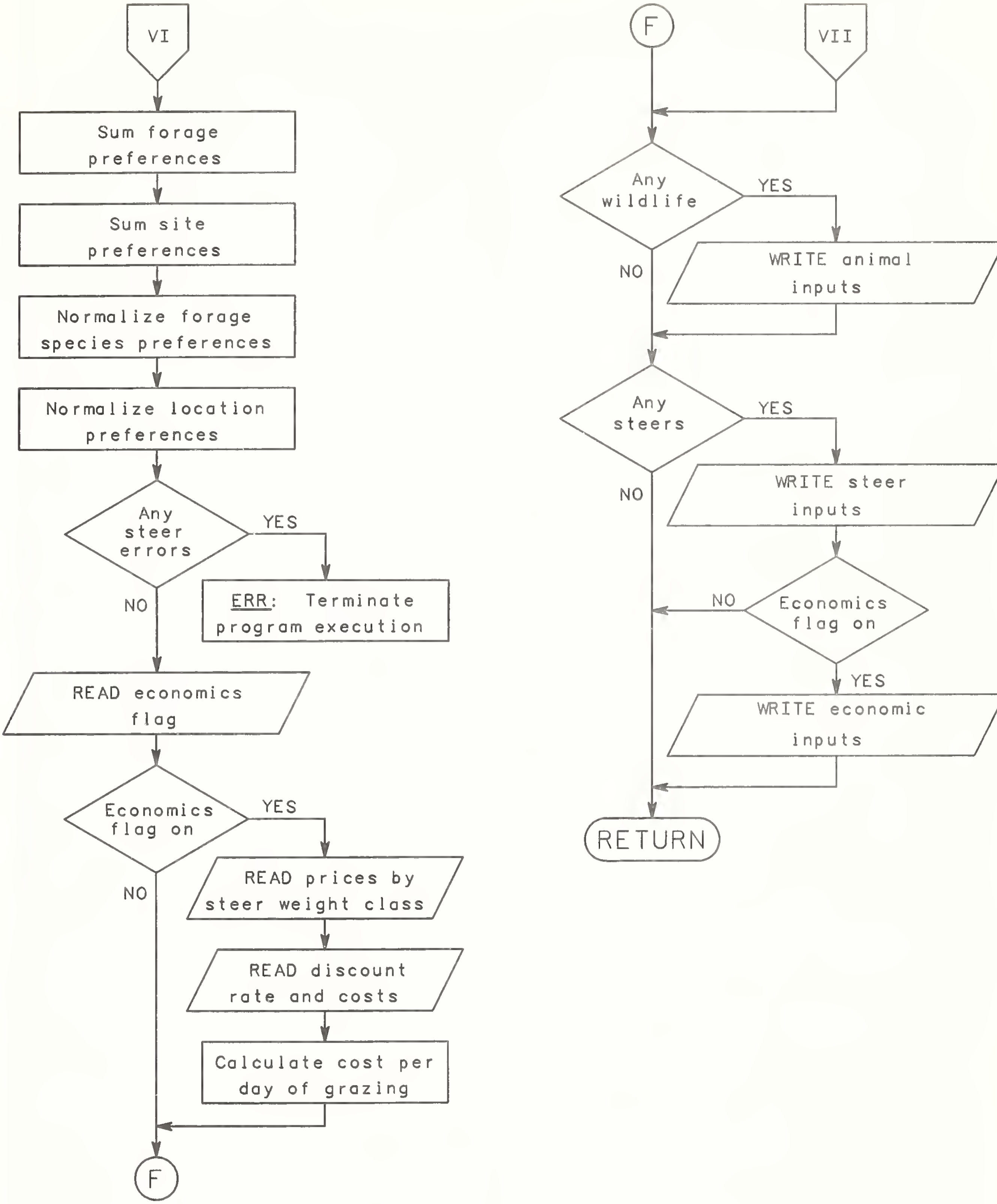


Figure 2.41--Continued
Subroutine USER: Initialization of the model.

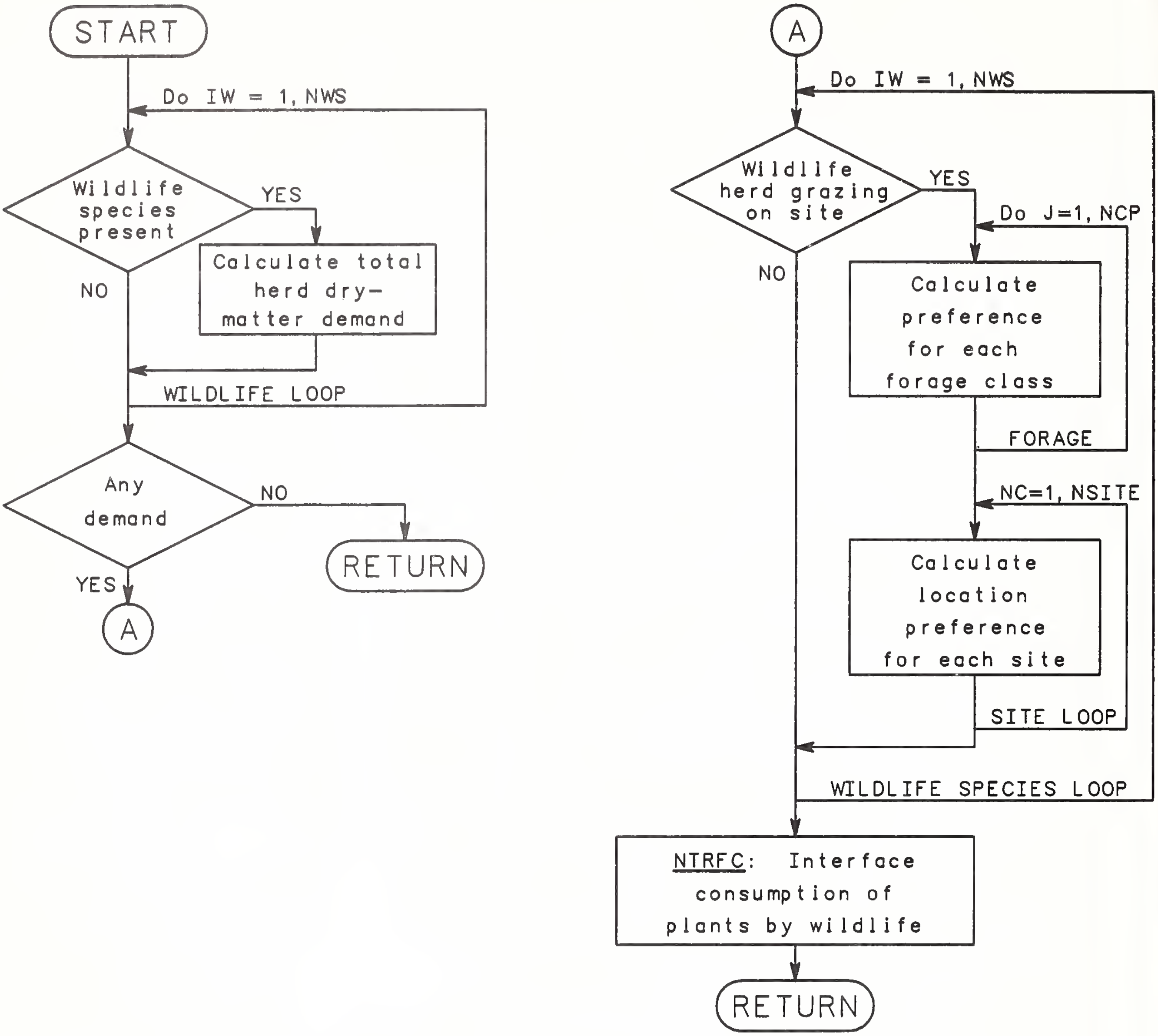


Figure 2.42
Subroutine WLDLF: Allow for consumption of plants by wildlife.

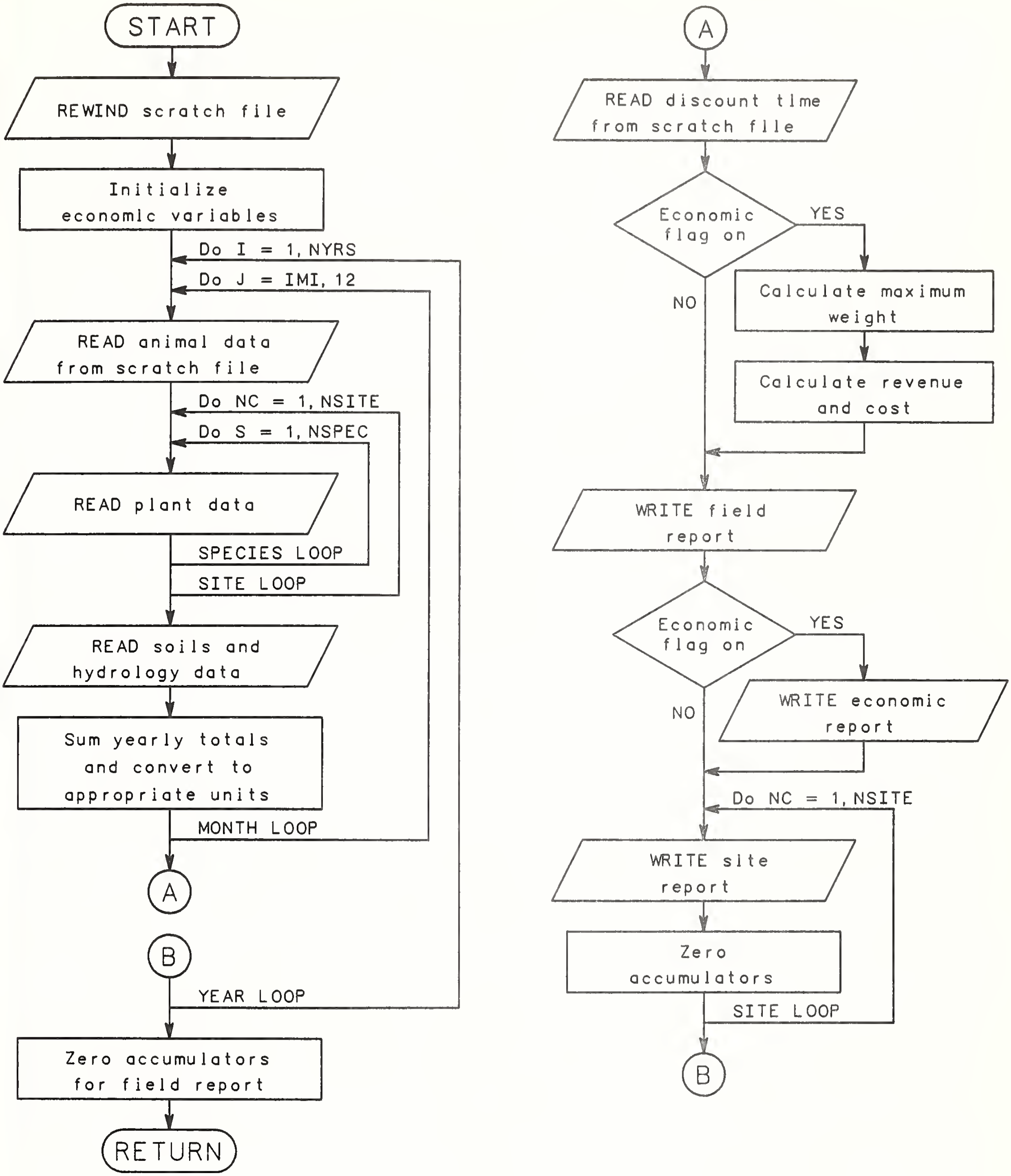


Figure 2.43
Subroutine YRREP: Produce yearly report.

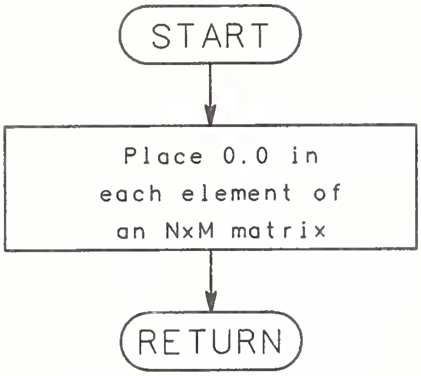


Figure 2.44
Subroutine ZERO:
Zero an N by M
matrix.

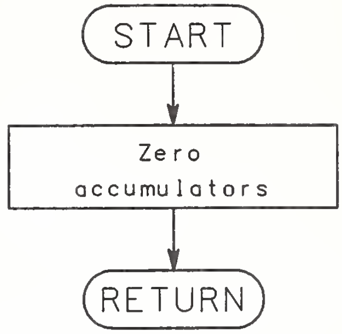


Figure 2.45
Subroutine ZERO19:
Zero accumulators.

This feature of allowing the user to specify the data files offers the flexibility of using many sets of data. For example, the user may plan a series of simulation experiments using a different plant parameter file for each simulation. Instead of renaming each plant file to a single common name recognized by the program or compiling the program every time a new file is used, he or she can use each file as needed by simply specifying the name each has in his disk space. The same may be done with any of the initialization files or with the climate file.

The SPUR program then opens three model definition and initialization files and a climate file. The three definition and initialization files for the three major components of the SPUR model are: (1) the parameters for the soils, hydrology and snowmelt subprograms; (2) the parameters for the plant subprograms; and (3) the parameters for the wildlife and domestic animal subprograms. A fourth file which reads the daily climate information is also formally opened. LUN's for these four files are coded in the program as LUN 3 for the animal information, LUN 4 for the climate information, LUN 8 for the hydrology information, and LUN 9 for the plant information.

The data sets for the three initialization files are described next.

The Hydrology-Component Input File

For the field-scale version of SPUR, the hydrology-component simulates the water balance on individual sites. Essentially, the routines are from the upland hydrology algorithms described by Renard et al. (Part I, chapter 3 of this volume). Channel systems have been ignored to reduce input requirements and allow simulation of allotment management practices which may cross several watershed boundaries. The sacrifice is that a true water balance is not maintained because water is allocated to sinks such as runoff and/or deep percolation, when in fact, the water in these stores may have been lost through transmission losses in a channel or appeared as streamflow via subsurface return flow. Another limitation to obtaining a complete water balance is that sites do not have to be contiguous. This prevents a more complete description of the water balance because runoff and recharge from upslope sites cannot be accommodated by the computer code using the current algorithms.

The estimation of erosion by MUSLE has been eliminated from the field-scale version of SPUR because some necessary variables cannot be defined under the current structure. The user could incorporate concepts such as unit slope length to predict relative erosional rates across sites, but the inability to move water from upslope areas onto downslope sites would be a major constraint.

Table 2.3 lists the variables, the format, and the description for each record in the hydrology-component input file. Record 1 of the hydrology input file holds the title of the current simulation. A maximum of 80 characters can be used for the title. Record 2 is the simulation experiment control card. The field size, starting time, and the output options which are controlled by the print switches IP1 through IP7, inclusive, are read from this record. The print switches are described in detail below. Record 3 is the format for the climate data which must be less than 80 characters.

The following requirements are listed to explicitly inform users of limitations for inputs into the hydrology initialization file. Some of these will result in an error being generated by the SPUR code (see Part II, chapter 8).

- The first two soil layers must each be 3.0 inches (7.5 cm) in thickness.
- The rooting depth should not extend into the last or bottom soil layer.
- The value for SM3 must be less than the value for SMO.
- The value for SM15 must be less than the value for SM3.
- The value for STF must be between 0.0 and 1.0, inclusive.

The Climate Input File

The SPUR model is driven by the variables of precipitation, maximum temperature, minimum temperature, solar radiation, and wind run. These variables must be supplied to the program code, one record per simulated day, each record containing the five variables in the order given. The format for reading the climate file is read as the third record in the hydrology and soils initialization data file (table 2.3.) Making the format variable allows the user to use different weather files each with different formats to drive the model without recompiling the model between simulation experiments.

The format for this file as shown in the tables in the example data sets (Part II, chapters 10 and 11) is 11X,5F10.5 which means skip 11 spaces on each record then read five variables in F10.5 format on that record. The user may change this format to allow his or her particular data set(s) to be read by the model. The user is referred to Part II, chapter 4, of the SPUR User Guide for a discussion of how to generate the climate file.

The Plant-Component Input File

The plant component of the SPUR model is a deterministic set of equations and relationships that can simulate the dynamics of both cool-season (C_3) and warm season (C_4) plants. The model processes each plant species in the simulation in exactly the same manner (with small exceptions for computational efficiency); all species growth, death, and physiological dynamics are calculated the same way, no matter whether the species is C_3 or C_4. To simulate the differences between plant species found on the rangeland (for example, the species' responses to moisture, nutrients, and to abiotic variables), the user must supply a set of

Table 2.3
Simulation control and hydrology-component input for the field-scale version of SPUR

Record number	Format	Variable name and description
RECORD 1	(80A1)	WID- title of the simulation.
RECORD 2	(5I5,F10.5,I5,7I2)	
	I5	IFYR- first year of the simulation.
	I5	NYRS- number of years to simulate.
	I5	NSITE- number of sites on the simulated field.
	I5	INIM- initial month simulation begins.
	I5	IDAY- initial day simulation begins.
	F10.5	AREA- area of entire field (acres).
	I5	KONVRT- convert temperatures and precipitation from metric to English units.
	I2	IP1- daily-report print flag.
	I2	IP2- monthly and yearly report print flag.
	I2	IP3- additional soil- and hydrology-information print flag.
	I2	IP4- plant-component carbon-submodel information print flag.
	I2	IP5- plant-component nitrogen-submodel information print flag.
	I2	IP6- steer forage-harvest and growth information print flag.
	I2	IP7- wildlife forage-harvest information print flag.
RECORD 3	(80A1)	FMT- format to read climate file.
************* RECORDS #04 THROUGH #11 TO BE REPEATED FOR EACH SITE ***		
RECORD 4	(2I5)	
	I5	IRSITE- site number.
	I5	NMSL- number of soil layers for the site (maximum of 8).
RECORD 5	(8F10.5)	
	F10.5	SAREA- area of site (acres).
	F10.5	CNI- condition I curve number.
	F10.5	RD- rooting depth (inches).
	F10.5	CONA- soil evaporation parameter for ET (in/d**0.5).

Table 2.3--Continued
Simulation control and hydrology-component input for the field-scale version of SPUR

Record number	Format	Variable name and description
RECORD 5--Continued		
	F10.5	ASPECT- aspect of site for radiation adjustment (azimuth in degrees).
	F10.5	SLOPE- slope of site for solar radiation adjustment (ft/ft).
	F10.5	GR- mulch (residue) cover factor.
	F10.5	CF- crack factor for crack-flow calculations (decimal fraction).
RECORD 6	(8F10.5)	
	F10.5	STF- fraction of field capacity (in this case, plant available water) in initial soil moisture (decimal fraction).
RECORD 7	(8F10.5)	SMO- porosity of the soil layer; enter NMSL values (maximum of 8).
RECORD 8	(8F10.5)	SM3- 1/3-bar volumetric water content for the layer; enter NMSL values (maximum of 8).
RECORD 9	(8F10.5)	SM15- 15-bar volumetric water content for the layer; enter NMSL values (maximum of 8).
RECORD 10	(8F10.5)	SLSC- saturated-soil hydraulic conductivity for the layer; enter NMSL values (maximum of 8, in/h).
RECORD 11	(8F10.5)	SLDTH- thickness of soil layer (inches); enter NMSL values (maximum of 8); same as THK in Part I.
RECORD 12	(8F10.5)	
	F10.5	DLAT- latitude of the field (degrees).
	F10.5	SELE- elevation of the field (ft).
	F10.5	TELE- elevation of the temperature measurement station (ft).
RECORD 13	(8F10.5)	
	F10.5	SCF- snow gage-catch correction factor.
	F10.5	MFMAX- maximum-melt factor for nonrain periods (mm/day-°C).
	F10.5	MFMIN- minimum-melt factor for nonrain periods (mm/day-°C).
	F10.5	UADJ- wind-adjustment factor for rain-on-snow periods (mm/mb-h).

Table 2.3--Continued
Simulation control and hydrology-component input for the field-scale version of SPUR

Record number	Format	Variable name and description
RECORD 13--Continued		
	F10.5	SI- maximum-accumulated-snow-water equivalent above which there is 100% snow cover.
	F10.5	ADPT- areal depletion curve type number, values range from 1 through 6 with fractional values interpolated.
	F10.5	NMF- maximum negative melt factor (mm/°C).
	F10.5	TIPM- weight applied to preceding-period temperature to calculate current snowpack temperature; in the range 0.0 to 1.0.
RECORD 14	(8F10.5)	MBASE- temperature for nonrain melt (°C).
	F10.5	PXTEMP- temperature to differentiate rain from snow (°C).
	F10.5	PLWHC- liquid-water holding capacity of the snowpack; in the range 0.0 to 1.0.
	F10.5	DAYGM- constant daily melt at snow-pack interface (mm).
RECORD 15	(8F10.5)	WE- field snow-water equivalent at the start of the simulation (mm).

parameters and critical values for each plant species to be simulated. These parameters and critical values are used to distinguish the physiological and ecological differences between plants and they are in effect for the entire simulation. (See Part I, chapter 6 and Part II, chapter 6.)

The plant component also controls the calculation of certain variables on the site being simulated. This part of the model is also general and deterministic. Such information as soil-organic nitrogen concentration, accumulated litter, and so forth, is calculated in the plant-component submodel.

Up to seven plant species or functional groups may be included in any one simulation. The user may have up to seven species at each site but no more than seven plant species may be used over the entire field. The user-supplied parameters and critical values for each species are used for all sites on the simulated field.

A maximum of nine sites may be included in any one simulation. One site is required for each simulation, making, in this case, the site equal to the field. For each site, the user must supply the starting levels in four state variables per simulated plant species. These constitute the beginning phytomass compartments for each species and are stored in the two-dimensional array PHYTM. Again, the user must supply these four-state-variable levels on a per-site basis.

Additionally, the user must supply site-specific (but not species-specific) variables for each site. These are the beginning values for soil inorganic matter (SNIO), dead roots (DROOTS), accumulated litter (ALIT), and soil organic matter (AORG).

Also, six variables which are neither species-specific nor site-specific must be supplied. These variables (the vector PNS) control the rates of decomposition and are assumed to be independent of plant species or site(s) on the field.

Table 2.4 lists the variables, the format, and the description for each record in the plant-component input file.

Table 2.4
Plant-component input for the field-scale version of SPUR

Record number	Format	Variable name and description
RECORD 1	(5I5,2F10.5,2I5)	
	I5	NSPEC- number of plant species.
	I5	NPARAM- number of parameters per plant species.
	I5	NCRITS- number of critical values per plant species.
RECORDS 2-8	(A80)	ASPEC- species name (one RECORD per species to a maximum of NSPEC).
RECORD 9	(8F10.5)	$P_{1,S}$- theoretical maximum net photosynthetic rate (mg dm^{-2} h^{-1}).
RECORD 10	(8F10.5)	$P_{2,S}$- light-use efficiency coefficient (m^2 W^{-1}).
RECORD 11	(8F10.5)	$P_{3,S}$- maximum temperature for positive plant activity (°C).
RECORD 12	(8F10.5)	$P_{4,S}$- optimum temperature for positive plant activity (°C).
RECORD 13	(8F10.5)	$P_{5,S}$- minimum temperature for positive plant activity (°C).
RECORD 14	(8F10.5)	$P_{6,S}$- photosynthetic-activity water potential (-bars).
RECORD 15	(8F10.5)	$P_{7,S}$- drought-tolerance coefficient (dimensionless).
RECORD 16	(8F10.5)	$P_{8,S}$- proportion of photosynthate sent to roots (dimensionless).
RECORD 17	(8F10.5)	$P_{9,S}$- maximum root-to-shoot ratio (dimensionless).
RECORD 18	(8F10.5)	$P_{10,S}$- wind-tolerance coefficient (km^{-1}).
RECORD 19	(8F10.5)	$P_{11,S}$- precipitation-tolerance coefficient (cm^{-1}).
RECORD 20	(8F10.5)	$P_{12,S}$- proportion of phytomass susceptible to trampling (dimensionless).
RECORD 21	(8F10.5)	$P_{13,S}$- susceptibility of standing dead to trampling (ha an^{-1}).
RECORD 22	(8F10.5)	$P_{14,S}$- susceptibility of green shoots to trampling (ha an^{-1}).
RECORD 23	(8F10.5)	$P_{15,S}$- proportion of green shoots susceptible to death (dimensionless).
RECORD 24	(8F10.5)	$P_{16,S}$- phytomass conversion factor (m^2 g^{-1}).

Table 2.4--Continued
Plant-component input for the field-scale version of SPUR

Record number	Format	Variable name and description
RECORD 25	(8F10.5)	$P_{17,S}$- proportion of photosynthate sent to propagules (dimensionless).
RECORD 26	(8F10.5)	$P_{18,S}$- proportion for translocation from roots to shoots (TRS) (dimensionless).
RECORD 27	(8F10.5)	$P_{19,S}$- germination proportion (dimensionless).
RECORD 28	(8F10.5)	$P_{20,S}$- maintenance-respiration coefficient (mg g^{-1} day^{-1}).
RECORD 29	(8F10.5)	$P_{21,S}$- proportion of additional shoot death after senescence (dimensionless).
RECORD 30	(8F10.5)	$P_{22,S}$- NOT USED.
RECORD 31	(8F10.5)	$P_{23,S}$- seed-mortality proportion (dimensionless).
RECORD 32	(8F10.5)	$P_{24,S}$- root-respiration proportion (dimensionless).
RECORD 33	(8F10.5)	$P_{25,S}$- root-mortality proportion (dimensionless).
RECORD 34	(8F10.5)	$P_{26,S}$- minimum percent nitrogen for photosynthesis (dimensionless).
RECORD 35	(8F10.5)	$P_{27,S}$- photosynthetic efficiency controlled by plant nitrogen (dimensionless).
RECORD 36	(8F10.5)	$P_{28,S}$- maximum-nitrogen-uptake coefficient (g N g^{-1} day^{-1}).
RECORD 37	(8F10.5)	$P_{29,S}$- nitrogen-use efficiency coefficient (m^2 g^{-1}).
RECORD 38	(8F10.5)	$CRIT_{1,S}$- maximum leaf area of green shoots (°C).
RECORD 39	(8F10.5)	$CRIT_{2,S}$- temperature for frost kill (°C).
RECORD 40	(8F10.5)	$CRIT_{3,S}$- temperature for TRS (°C).
RECORD 41	(8F10.5)	$CRIT_{4,S}$- water potential for TRS (bars).
RECORD 42	(8F10.5)	$CRIT_{5,S}$- water potential for seed germination (bars).
RECORD 43	(8F10.5)	$CRIT_{6,S}$- day that seed production begins.
RECORD 44	(8F10.5)	$CRIT_{7,S}$- day that senescence begins.
RECORD 45	(8F10.5)	$CRIT_{8,S}$- day that senescence ends.

Table 2.4--Continued
Plant-component input for the field-scale version of SPUR

Record number	Format	Variable name and description
**************	RECORDS 46 THROUGH 50 TO BE REPEATED FOR EACH SITE **	
RECORD 46	(8F10.5)	
	F10.5	SNIO- soil inorganic nitrogen (g m^{-2}).
	F10.5	DROOTS- dead roots (g m^{-2}).
	F10.5	ALIT- litter (g m^{-2}).
	F10.5	AORG- soil organic matter (g m^{-2}).
RECORD 47	(8F10.5)	$PHYTM_{1,S}$- standing green phytomass (g m^{-2}).
RECORD 48	(8F10.5)	$PHYTM_{2,S}$- live root phytomass (g m^{-2}).
RECORD 49	(8F10.5)	$PHYTM_{3,S}$- propagule phytomass (g m^{-2}).
RECORD 50	(8F10.5)	$PHYTM_{4,S}$- standing dead phytomass (g m^{-2}).
RECORD 51	(8F10.5)	
	F10.5	PNS_1- proportion of dead roots susceptable to decomposition (dimensionless).
	F10.5	PNS_2- proportion of litter susceptable to decomposition (dimensionless).
	F10.5	PNS_3- proportion of organic matter susceptable to decomposition (dimensionless).
	F10.5	PNS_4- moisture tolerance of denitrification (-bars).
	F10.5	PNS_5- decomposition water potential (-bars).
	F10.5	PNS_6- drought-tolerance coefficient for decomposition (dimensionless).

The Animal-Component Input File

The SPUR model has the capability to simulate the effects of grazing by wild as well as domestic animals. Using a set of equations and relationships, the model can also simulate the physiological growth of a steer and then multiply that information by the size of the herd of grazing steers to establish herd weight gain or loss and the (fixed) economic return therefrom.

Wildlife

The first record read from the animal-component initialization file is the number of wildlife species (NWS) to be used in the simulation experiment. A maximum of 10 wildlife species may be used in any one experiment. If the number of wildlife species is zero, the program skips the remaining wildlife-parameter read statements and begins reading information for the domestic grazing animals.

If one or more wildlife species is present, the user then must supply the size of the herds of each wildlife species (POPSZ). The user then indicates the preference for location (PLOC) of each wildlife species, 1.0 being equivalent to 100 percent preference and 0.0 being no preference for a site. Note that a preference for each site must be specified for each wildlife species. Also, all preferences for location must sum to 1.0

for each wildlife species.

The user then specifies the preference of each wildlife species for each forage class (PREF). A class here is defined as either standing green biomass or standing dead biomass of a simulated plant species. Thus, if seven plant species or functional groups are being used in a simulation experiment, a total of 14 forage classes would be available for wildlife consumption. Again, a value of 1.0 indicates a 100 percent preference for forage class while a 0.0 indicates no preference for a forage class. A preference for each forage class by each wildlife species must be supplied. Also, the preferences expressed by each wildlife species for all forage classes must sum to 1.0.

Next, the user specifies the Julian day on which each wildlife species arrives at the field (TIN) and the Julian day on which it departs (TOUT). (See the discussion of errors 22 and 21 in Part II, chapter 8, for the limitations on these two variables.)

The final wildlife initial variable the user must supply is the dry-matter intake (DMI) for one member of each wildlife species (or herd). This feature allows the use of organisms with large population sizes but relatively small daily forage requirements (for example, rodents) to harvest the forage, as well as allowing use by larger animals (for example, pronghorn antelope) which have greater forage requirements but relatively smaller population sizes.

Note that SPUR does not physiologically grow wildlife species (see Part I, chapter 7). Rather, the model uses wildlife as a sink for the removal of vegetation. Also, only standing green and standing dead biomasses are considered to be forage available for harvest by wildlife. No mechanism exists in the model to remove seeds from a site by granivorous rodents or insects.

Domestic Animals

The SPUR model contains the formulations required to physiologically add to or subtract adipose tissue from a simulated growing steer. Other domestic animals which are typically allowed to graze rangeland are not included in the formulations. If the user wishes to graze sheep, for example, he or she must convert the body weight of a sheep to the body weight of a steer to get a "steer equivalent." So, suppose the user wants to graze 50 sheep and that one steer weighs about the same as five sheep. The user must then enter the number of domestic grazing animals as 10. To simulate sheep grazing rather than steer grazing, the user-supplied preference vectors should reflect grazing habits of sheep. When interpreting the results of the simulation experiment, the user must realize that they do not show the growth of sheep, but are instead estimates of growth for the "steer-equivalent" animals.

The SPUR program requires the number of steers (NUM) to be used in the simulation experiment. If this value is zero, the rest of the read statements for the steer initial conditions are not executed. If steers are present for the simulation, the program reads a flag (ISUP) indicating whether the steer diet is to be supplemented. Next, the user supplies the asymptotic weight of a mature steer of the breed being simulated (WMA), the Julian day the steer herd is to begin grazing (TINS), the Julian day on which the animals are removed from the field (TOUTS), the weight of an average steer (WT), and its age in Julian days (TAVG) of the average steer on the day the herd begins grazing.

Next, if the supplementation flag is given a value of one, the user must supply the amount of the supplement in kilograms (SUP), the digestibility of the supplement (DIGS), and the Julian day when the supplementation begins (TS1) and ends (TS2). If the diet supplementation flag is not turned on, then this information must be omitted.

Next, the user provides the preference of the steer for each forage class, all preferences summing to 1.0 (vector A1). Then, the physical limitation for each forage class must be supplied (vector A2). Also, preference for each site must be supplied (vector A3), and the physical limitations for access to each site must be supplied (vector A4). The user is directed to the discussion of the possible errors that may be generated for the steer initialization component in Part II, chapter 8.

The brief amount of information needed to run the economics of the simulated rangeland is required next. First, the economics flag (ICON) must be set to one. If it is not, the rest of the information is not read. The next record holds the price per weight class of steers (vector PRICE). The final record supplies the discount rate (DRATE) and the costs (COSTS). If no steers are grazed, no economic information is calculated.

Table 2.5 lists the variables, the format, and the description for each record in the animal-component initialization file.

SPUR OUTPUT FILES

The SPUR code provides the user with a number of options for viewing the output of a simulation experiment. These options are described below. No matter what option the user selects, however, he will always get a report for the input variables. This output is written to device 16, a device which is formally opened in subprogram IOSET. The file written to it is called SUMARY.DAT. (Please no letters about SUMARY being misspelled! This was done purposely to keep all file names and variable names within the program code to six characters or less.)

The report written to SUMARY includes definition information for the simulation experiment; such things as number of years to simulate, the title, and so forth; the soils- and hydrology-component information; the plant-component information; and, if there are wildlife and/or grazing steers, that information. An example of this report is

given in figure 11.7 of the User Guide (Part II). (The numbers in the examples shown in this section of the User Guide are not meant to be used or interpreted as actual SPUR results. They are to illustrate the formats available for the SPUR output.)

This report is written for each simulation primarily so that the user may check to see that the input to the code is being read properly. This LUN also receives any error messages generated by SPUR. For these reasons, the user should not attempt to deactivate this device by changing the source code.

The SPUR model processes a large number of state variables and calculates numerous rates during one iteration, the number being dependent on which model component is used, this, in turn, being dependent on such things as a presence of snow cover, grazing steers, and so forth. Specific users may be interested in all of these levels and rates and want them to be output to some device for later study. Other users may only be interested in daily weight gain of steers during the grazing season and wish only that output, the remaining being superfluous. The SPUR computer code has been designed so that a number of output options may be used to view the condition of the range ecosystem, or parts thereof, during an experiment.

Understand, however, that not all variables can be output to satisfy the demand of every user. Table 2.6 and the discussion below will give the user an idea of the SPUR model's output capabilities. The output options described below have been incorporated at the suggestion of users who have experimented with preliminary versions of the SPUR code and reflect their preferences for output information. While not every state variable or rate has been coded to be output, those that are give good indications of the processes modeled by SPUR and the time paths they follow. (By using the dictionaries in the comment cards in the listing of the SPUR source code and by reading and understanding the "Documentation" (Part I) for the model, the user may, of course, write his or her own code to output the variables he or she wishes to study.)

Logical Unit Device Numbers

Twenty years ago, when many of the contemporary users of mainframe computers were learning how to use a computer, the number of devices that could be assigned to a specific job was limited. A typical job, most certainly run in batch, accessed the card reader, the line printer, perhaps a tape drive, maybe a card punch or paper-tape punch, and one or two other peripherals. Each of these devices had assigned to it a logical unit device number or LUN. The number of the LUN's was usually limited by the facility and the value of the LUN's (6 for the printer, and so on), a fixed limitation also set by the facility.

Modern digital computers can often be programed to accommodate many LUN's and have the files written to a mass storage device. Time-sharing via an interactive terminal can then be used to view these files which can then be printed, stored, or plotted. The project modeler has developed the SPUR code on a Digital Equipment Corporation (DEC) VAX 11/750. That machine can be configured to allow a user upward of 100 logical devices. We realize that not everyone will have machines that allow this many LUN's to be used. Those users should consult table 2.6 and ascertain which device numbers are being used to print the information in which they are interested and make the appropriate changes in the SPUR source code.

SPUR User Output Options

To begin, there are seven output print flags. If the user does not set any of the seven print flags to a number other than zero, SPUR generates the message:

W A R N I N G - NO PRINT SWITCH
HAS BEEN TURNED ON

(Switch and flag are used interchangeably here.) This message is printed at the head of the SUMARY file, before printing the simulation definition and parameters. The program does not terminate execution because some users may wish to run the model straight through to test for abnormal termination without the expense of writing any output to disk. If the user specifies output from the wildlife or the livestock components but has told the model that no herbivores will be grazing during the experiment, SPUR will write the same message to the same file at the end of the plant component parameters and initial conditions. (See the discussion of switches IP6 and IP7 below.)

The user is directed to the description of the soils and hydrology input file and to table 2.3. The first record of that file is the title of the simulation experiment. The second card is in 5I5,F10.5,I5,7I2 format. The first five I5 fields read the first year of the simulation, the number of years of the simulation, the number of sites, the starting month of the starting year, and the starting day of the starting month of the starting year, respectively. The F10.5 field reads the total acreage of the simulated field. The next I5 field reads the english/metric conversion switch. Then, there are seven I2 fields, each of which reads a print flag, the value of the flag directing the printing of specific output variables.

Output Device Considerations

The first two output-option switches (IP1 and IP2) cause output to be written to a scratch file on LUN 10. At the end of the simulation, this device is rewound and these variables are then read and written, in report form, to LUN 16 if IP1 or IP2 is set to 1. The variables written to the disk are unformatted, which constitutes a savings in hard-coded array storage within the program code itself. There are two drawbacks with this method of storing and writing output information, however. The first is that the longer an experiment is set to run, the more output information is stored on disk. For long simulation exper-

Table 2.5
Animal-component input for the field-scale version of SPUR

Record number	Format	Variable name and description
RECORD 1	(2I5)	NWS- Number of wildlife species (maximum of 10).
******************** OMIT RECORDS 2 THROUGH 6 IF NWS = 0 *************		
RECORD 2	(10F8.0)	POPSZ- population size of each wildlife herd (one per NWS).
RECORD 3	(8F10.5)	PLOC- location preference per wildlife herd per site.
RECORD 4	(8F10.5)	PREF- preference for live and dead forage per wildlife herd.
RECORD 5	(8F10.5)	
	F10.5	TIN- date each wildlife herd begins to graze.
	F10.5	TOUT- date each wildlife herd stops grazing.
RECORD 6	(8F10.5)	DMI- daily dry-matter intake per single member of the wildlife herd (kg).
RECORD 7	(2I5)	NUM- number of steers.
******************* OMIT RECORDS 8 THROUGH 17 IF NUM = 0 ************		
RECORD 8	(2I5)	ISUP- steer diet supplement flag.
RECORD 9	(8F10.5)	
	F10.5	WMA- mean asymptotic weight for a mature steer (kg).
	F10.5	TINS- day that grazing starts.
	F10.5	TOUTS- day that grazing ends.
	F10.5	TAVG- age of steer on TINS (days).
	F10.5	WT- weight of steer on TINS (kg).
************************ OMIT RECORD 10 IF ISUP = 0 ********************		
RECORD 10	(8F10.5)	
	F10.5	SUP- amount of daily diet supplement per head (kg).
	F10.5	DIGS- digestibility of supplement.
	F10.5	TS1- day to start supplementing.
	F10.5	TS2- day to end supplementing.
RECORD 11	(8F10.5)	A1- steer preference vector for forage (live/dead).
RECORD 12	(8F10.5)	A2- steer limitation vector for forage.

Table 2.5--Continued
Animal-component input for the field-scale version of SPUR

Record number	Format	Variable name and description
RECORD 13	(8F10.5)	A3- steer preference vector for site.
RECORD 14	(8F10.5)	A4- steer limitation vector for site.
RECORD 15	(2I5)	CON- economics calculation and report flag.
**************	OMIT RECORDS 16 AND 17 IF NUM = 0 OR IF ICON = 0 ********	
RECORD 16	(8F10.5)	PRICE- price per weight class.
RECORD 17	(8F10.5)	
	F10.5	DRATE- discount rate.
	F10.5	COSTS- cost per head per month.

iments on machines that are limited in diskstorage space, this imposes constraints on the duration of the period simulated. The second drawback is that if for some reason the program does not terminate execution normally, and depending on the machine, the information written to the scratch file is often lost, meaning that no simulation results are available for analysis.

The remaining output-option switches (IP3, IP4, IP5, IP6, and IP7) do use fixed arrays hard coded in the SPUR program. The variables that the user can request to be output using these print switches are stored in these arrays and written to the specified LUN at, depending on the switch and the value it has been assigned, the end of a simulation day or the end of a simulation year. This means that if SPUR terminates execution abnormally, all information from an experiment is not necessarily lost. There are two drawbacks with use of these switches. The first is that storage in computer memory is allocated at compile time regardless of whether the user sets the print switches to values greater than zero. Computer memory again becomes a constraint. The second drawback is that each output file written by using these options requires a different LUN. On some machines this is not a special problem. On others, however, the user is limited to the number of devices he or she may assign or access, making use of all these print switches at the same time impossible. The user should consult his reference manuals and computer systems manager to ascertain the number of logical unit devices he or she may access during a SPUR experiment.

Print Switch IP1

Print switch IP1 may have two values. The first, a zero, means the program path of execution skips the WRITE statements in the last part of the main program and in the subroutine DAYREP. If the switch is set to a value of 1, these WRITE statements are executed every simulated day. An example of the output obtained from IP1 being set to 1 is shown in figure 2.46. The user should note the following: IF IP1 IS SET TO 1, FIGURE 2.46 WILL BE WRITTEN EVERY DAY FOR EVERY SITE. That is, a page of output is written for each site simulated, to a maximum of nine sites, meaning that up to nine pages of output can be generated per simulated day if the maximum number of sites is used.

The daily report shows the precipitation in inches for that day, the maximum and minimum temperatures (°F), the solar radiation (ly), and the snow water equivalent in inches. Then on a per-site basis, the report shows potential evapotranspiration (in), the total leaf area index, potential plant transpiration (in), actual plant transpiration (in), potential soil evaporation (in), the rooting depth (in), and the available water (in). Also printed on a per-site, per-species basis are each of the four plant-component compartments of the carbon model which have species identity. These are aboveground green biomass, live root biomass, propagule biomass, and standing dead biomass, all with the units of grams per square meter. Also printed is the total site, aboveground, live biomass in the same units.

Print Switch IP2

The second print switch IP2 controls the monthly and the yearly output summaries, written to the file SUMARY, on LUN 16 in report form. A value for IP2 of zero means this report is omitted. A value of 1 for IP2 means the report is printed. The information printed on a field-wide basis is monthly and yearly totals for precipitation (in), infiltration (in), potential evapotranspiration (in), soil evaporation (in), plant transpiration (in), deep percolation (in), and plant-available water (in). Also reported is the aboveground plant biomass (kg) on the last day of each month.

Table 2.6
Field-scale version of SPUR print switches, output options, and logical unit numbers

Print switch		Condition	Result
IP1	=	0	no output, subprogram DAYREP report not called
	=	1	subprogram DAYREP report called and information written to SUMARY file (LUN 16) daily, in report form; variables are day, year, precipitation, maximum temperature, minimum temperature, solar radiation, snow water equivalent and then a report on a per-site basis which includes the values for potential evaporation, leaf area index, potential plant transpiration, actual plant transpiration, potential soil evaporation, actual soil evaporation, root depth, available water, aboveground standing green phytomass for all plant species, and the total aboveground standing dead for the site
IP2	=	0	subprogram YRREP not called and no yearly or monthly summaries written
	=	1	subprogram YRREP called and yearly/monthly summaries written to SUMARY file (LUN 16), in report form; monthly totals and yearly totals on a field and for each site are precipitation, infiltration, potential evaporation, soil evaporation, plant transpiration, deep percolation, and plant-available water; month-end aboveground plant biomass is written for each month, and if steer grazing is simulated, the weight of an average steer at month-end and grazing-season weight gain of a steer is printed; if steer grazing is simulated and the economics report flag (ICON) is turned on, a yearly report is written which includes the totals for the steer purchase cost, the annual variable cost, the total annual costs, the pounds of beef sold, the gross revenue, net revenue, the net present value, and the cummulative net present value
IP3	=	0	no output, subprogram DETAIL not called
	=	1	subprogram DETAIL is called and evapotranspiration information is written to device 18 daily; the variables are year, site, day, potential evapotranspiration (E0), potential soil evaporation (ES0), actual soil evaporation (ES), potential plant transpiration (EP0), actual plant tranpiration (EP), and total site leaf area (AL)
	=	2	subprogram DETAIL is called and selected abiotic variables written to device 20 daily; the variables are year, site, day, moisture tension in the upper 15 centimeters of the soil profile (bars), moisture tension in the wettest layer of the soil profile in which there are plant roots (bars), ten-day running-average air temperature (degrees C), and five-day running-average soil moisture tension in the upper 15 cm of the soil profile (bars)
	=	3	subprogram DETAIL is called and soil water content per-layer per-site per-day, in centimeters, is written to device 22 - (NOTE The upper two three-inch layers are summed and written in the first water-content column.)
IP4	=	0	no plant carbon model output is written, subprogram DETAIL not called
	=	1	subprogram DETAIL is called and selected plant carbon model variables are written to device 24 on a species-per-site and yearly basis; the variables are PEAK STANDING CROP, DATE FOR PEAK STANDING CROP, SUMMED SHOOT DEATH, SUMMED CARBON ASSIMILATION and SUMMED EMP (which is the effect of moisture on photosynthesis)
	=	2	subprogram DETAIL is called; variables written are the same as when IP4 = 1, plus additional plant carbon model variables are written to device 24 on a species-per-site and yearly basis; the variables are SUMMED NET PHOTOSYNTHESIS, SUMMED NIGHTTIME RESPIRATION, SUMMED ROOT RESPIRATION, SUMMED TRANSLOCATION FROM ROOTS TO SHOOTS, SUMMED TRANSLOCATION FROM SHOOTS TO ROOTS,

Table 2.6--Continued
Field-scale version of SPUR print switches, output options, and logical unit numbers

Print switch	Condition	Result
IP4 (Continued)	= 2	SUMMED ROOT MORTALITY, SUMMED ETD (effect of temperature on decomposition), and SUMMED EMD (effect of moisture on decomposition)
	= 3	subprogram DETAIL is called and daily output by species and site of the following variables, written to the specified devices: variable — device TRANSLOCATION FROM ROOTS TO SHOOTS — 26 TRANSLOCATION FROM SHOOTS TO ROOTS — 28 NET PHOTOSYNTHESIS — 30 EMP - effect of moisture on photosynthesis — 32 ETP - effect of temperature on photosynthesis — 34 ENP - effect of soil nitrogen on photosynthesis — 36 ETD - effect of temperature on decomposition — 38 EMD - effect of moisture on decomposition — 40
	= 4	subprogram DETAIL is called and compartments of the plant carbon model output every day by site, as described below, and written to CARBON.DAT; the variables which are written on a per-species basis are site, species, standing green, live roots, propagules, and standing dead; written on a per-site basis are dead roots, litter, organic matter, and inorganic nitrogen
	> 4	subprogram DETAIL is called and information produced is as when IP4 = 4, but output is on simulated days which are multiples of the switch value
IP5	= 0	no plant nitrogen model output, subprogram DETAIL not called
	= 1	subprogram DETAIL called and selected plant nitrogen model variables written to device 42 on a per-site basis at the end of the simulation year; the variables are PEAK N:C RATIO, DATE FOR PEAK N:C RATIO, SUMMED MINERALIZED NITROGEN, SUMMED FIXED NITROGEN, SUMMED EMNU (effect of moisture on nitrogen uptake), SUMMED ETNU (effect of temperature on nitrogen uptake), and SUMMED EMD (the effect of moisture on denitrification)
	= 2	subprogram DETAIL called and daily output of the following variables, by species and site, are written to the specified devices: variable — device EMNU - effect of moisture on nitrogen uptake — 44 ETNU - effect of temperature on nitrogen uptake — 46 FN - nitrogen fixed from the atomosphere — 48 EMDN - effect of moisture on denitrification — 50 MN - mineralized nitrogen — 52
	= 3	subprogram DETAIL is called and compartments of the plant nitrogen model output every day by site, as described below, and written to NITRO.DAT; the variables which are written on a per-species basis are site, species, nitrogen in standing green, N:C of standing green, nitrogen in live roots, and N:C of live roots; written on a site basis are nitrogen in dead roots, nitrogen in litter, nitrogen in organic matter, and inorganic nitrogen
	> 3	subprogram DETAIL is called and information produced is as when IP5 = 3, but output is on simulated days which are multiples of the switch value

(NOTE - Use of IP6 is valid only if NUM is greater than zero. SPUR will reset IP6 to zero if NUM is read as zero.)

Print switch	Condition	Result
IP6	= 0	no steer variables output, subprogram DETAIL not called

Table 2.6--Continued
Field-scale version of SPUR print switches, output options, and logical unit numbers

Print switch		Condition	Result
IP6	=	1	subprogram DETAIL called and selected livestock-component variables written to device 54 on a yearly basis; the variables are TOTAL WEIGHT GAIN FOR THE GRAZING SEASON in kilograms, SUMMED DIGESTIBLE-DRY-MATTER INTAKE in kilograms, and the dry matter harvested, in kilograms per hectare, for live and dead material for all forage species
	=	2	subprogram DETAIL is called and daily output of the total of each forage class (live and dead) harvested is output to device 56; the format is year, site, day, and then the live and dead forage harvested, in grams per square meter, on that day for each forage species
	=	3	subprogram DETAIL is called and daily output of selected livestock variables in report form is written to device 58; the variables are year, day, percent crude protein of all forage (live and dead) demanded by livestock (CPP), digestible dry matter of forage consumed by livestock (PDIG), amount of forage demanded by all steers, and weight (kg) of a single average steer
	=	4	subprogram DETAIL is called and year, site, day, and harvest of forage (live and dead) per forage species per-site is written on device 60
(NOTE - Use of IP7 is valid only if NWS is greater than zero. SPUR will reset IP7 to zero if NWS is read as zero.)			
IP7	=	0	no wildlife forage-harvest information output, subprogram DETAIL not called
	=	1	subprogram DETAIL is called and year, site, day, wildlife species number, and harvest of forage (live and dead) per forage species per-site is written on device 62

If the user is simulating grazing, the field report also shows the weight in kilograms of an average steer on the last day of the month and the grazing-season total weight gain (kg) for an average steer. Next, if grazing steers are simulated, and the value for ICON in the animal-component input file is set to 1, an economics report is generated for the field. That portion of the report shows the total expenditure for the steer herd, the annual variable cost, the total annual costs, the pounds of beef sold, the gross revenue, the net revenue, the net present value, and the accumulated present value. The units are in dollars.

The report continues to print monthly and yearly totals of the following variables on a per-site basis: precipitation (in), infiltration (in), potential evapotranspiration (in), soil evaporation (in), plant transpiration (in), deep percolation (in), plant-available water (in), above-ground plant biomass (kg), and erosion (kg). An example of the report produced when IP2 is set to 1 is shown in figure 11.7 of the User Guide (Part II).

Most of the remaining print switches cause variables manipulated by SPUR to be stored or accumulated in specific output variables. While this is transparent to the general user, it will be instructive for the user who wishes more detail to note that a number of output variables have been programed into the code, each with the two letters in sequence, OV. On either side of these variables are letters and numbers which tell to which SPUR component they belong. These letters to the left are H for hydrology and soils, P for plants, and A for animals. To the right of the OV may appear the letters C for plant carbon model, N for plant nitrogen model, S for steer variables, and W for wildlife variables. So, POVN4 refers to plant nitrogen output variable four and AOVW1 refers to animal/wildlife output variable one.

Calls to DETAIL are made from various control loops within the code to generate either daily or yearly information. Yearly information is produced in report form.

Print Switch IP3

The information written to the SUMARY file, controlled by IP2, is primarily of interest to hydrologists. True, some of the report deals with the plant and (when grazing is simulated) animal components but most of the information relates to the model hydrology dynamics. The function of this switch is to allow the user to more fully

```
DAY  :162          YEAR  :1971

PRECIPITATION (IN):   0.01181
MAXIMUM TEMP (F) :  80.60000
MINIMUM TEMP (F) :  41.00000
SOLAR RADIATION (LY) : 559.00000
SNOW WATER EQUIVALENT (IN) :    0.00000

REPORT FOR SITE NO. 1

POTENTIAL ET (IN):   0.23430
LEAF AREA INDEX   1.46109
POTENTIAL PLANT TRAN (IN):   0.11411
ACTUAL PLANT TRAN (IN):   0.11411
POTENTIAL SOIL EVAP (IN):   0.11715
ACTUAL SOIL EVAP (IN):   0.01181
ROOT DEPTH (IN):  18.00000
AVAILABLE WATER (IN):   1.14667

   WARM SEASON GRASSES            * 24.69042    5.23316    0.5641     0.02464
   COOL SEASON GRASSES            * 12.29565    0.38277    0.15085    0.00307
   WARM SEASON FORBS              *  0.18145    0.00469    0.00542    0.00004
   COOL SEASON FORBS              * 11.62801    0.64504    0.14055    0.00647
   SHRUBS                         * 16.29208   23.43146    0.17252    0.11902

TOTAL ABOVE GROUND LIVE BIOMASS (G/M**2):          65.08761

WEIGHT OF AN AVERAGE STEER (KG): 322.59296
CHANGE IN WEIGHT OF AN AVERAGE STEER (KG):   0.70319
```

Figure 2.46
Example of SPUR output when print switch IP1 is set equal to 1. (The single asterisks indicate that the values for the phytomass compartments have been moved to the left for this figure.)

output some of the hydrology and abiotic variables being used in the model. If the switch is set to zero, none of the following will be printed.

When the switch is set to 1, a single header line is written to LUN 18. Then it is followed by one record per simulated day with the following information, again written to LUN 18. The variables written are year, site, day, potential evaporation (ES0), actual soil evaporation (ES), potential plant transpiration (EP0), actual plant transpiration (EP), and total site leaf area (which is unitless). The user should be aware that this option will produce a file with the number of records equal to the number of days simulated plus one. An example is shown in Figure 2.47.

With the IP3 switch set to 2, the model produces abiotic information which is important for the hydrology/plant interface. The variables are written to LUN 20, one record per simulated day. The variables are year, site, day, moisture tension in bars at 15 cm in the soil profile, the moisture tension, in bars, in the wettest soil layer for which there are plant roots, the ten-day running-average air temperature (°C), and the five-day running-average soil moisture tension, in bars, in the upper 15 cm of the soil profile. An example of this output format is shown in Figure 2.48.

When IP3 is set to 3, the output written to device 22 is daily soil water content of each soil layer by site by day in centimeters. The first three variables for each record are simulation year, site, and day. The upper two soil layers are summed and are written in the fourth field (figure 2.49).

Print Switch IP4

This switch controls the output from the carbon submodel of the SPUR plant component. If it is set to zero, none of the following will pertain. When this switch is set to 1, these values are written to LUN 24: peak standing crop, the date for peak standing crop, the summed shoot death for the growing season, the summed carbon assimilation for the growing season (this is the growing season sum of the daily photosynthesis minus the night-time respiration and is equivalent to the above-ground net primary productivity), and the sum of the multiplier EMP. The latter is the effect of moisture on photosynthesis. It is calculated daily, as are all the multipliers. A value of unity means there is no stress for the plant on that day. (The user is directed to the plant component chapter in Part I for the methodolgy used in calculating the effect multipliers and for the way in which they are used by the model.) This information is written in report form, at the end of a simulated year on a per-species, per-site

YEAR	SITE	DAY	E0	ES0	ES	EP0	EP	AL
*								
1	1	140.000	0.211	0.105	0.027	0.057	0.057	0.818
1	1	141.000	0.298	0.149	0.000	0.083	0.083	0.836
1	1	142.000	0.197	0.099	0.099	0.056	0.056	0.855
1	1	143.000	0.085	0.043	0.043	0.024	0.024	0.860
1	1	144.000	0.249	0.124	0.124	0.073	0.073	0.876
1	1	145.000	0.224	0.112	0.086	0.067	0.067	0.893
1	1	146.000	0.283	0.141	0.116	0.086	0.086	0.910
1	1	147.000	0.225	0.112	0.052	0.069	0.069	0.926
1	1	148.000	0.246	0.123	0.022	0.077	0.077	0.941
1	1	149.000	0.209	0.104	0.000	0.067	0.067	0.956
1	1	150.000	0.178	0.089	0.000	0.057	0.057	0.970
1	1	151.000	0.254	0.127	0.000	0.083	0.083	0.984
1	1	152.000	0.266	0.133	0.000	0.088	0.088	0.997
1	1	153.000	0.273	0.136	0.000	0.092	0.092	1.010
1	1	154.000	0.197	0.098	0.000	0.067	0.067	1.029
1	1	155.000	0.171	0.086	0.000	0.060	0.060	1.049
1	1	156.000	0.278	0.139	0.000	0.100	0.100	1.076
1	1	157.000	0.238	0.119	0.000	0.088	0.088	1.112
1	1	158.000	0.284	0.142	0.000	0.110	0.110	1.162
1	1	159.000	0.212	0.106	0.000	0.087	0.087	1.225

Figure 2.47
Example of SPUR output when print switch IP3 is set equal to 1. The column headings appear in the output only once; the asterisk indicates that 139 lines of output have been removed for this figure.

1	1	140	-2.18933	-0.09461	9.01696	-1.39735
1	1	141	-3.31462	-0.10142	9.55382	-1.91560
1	1	142	-6.65421	-0.10885	10.15465	-3.04836
1	1	143	-0.32611	-0.04979	9.56668	-2.85077
1	1	144	-0.32096	-0.05302	9.38202	-2.56105
1	1	145	-0.35869	-0.05940	9.38236	-2.19492
1	1	146	-0.39848	-0.06578	9.05849	-1.61169
1	1	147	-0.49797	-0.07317	8.93507	-0.38044
1	1	148	-0.66673	-0.08012	9.60574	-0.44857
1	1	149	-0.99504	-0.08774	10.18427	-0.58338
1	1	150	-1.46158	-0.09503	10.66554	-0.80396
1	1	151	-2.11231	-0.10182	10.63250	-1.14672
1	1	152	-3.88963	-0.10930	10.69194	-1.82506
1	1	153	-8.38570	-0.11793	11.76132	-3.36885
1	1	154	-15.27623	-0.13358	12.67925	-6.22509
1	1	155	-20.69390	-0.15020	12.80377	-10.07155
1	1	156	-25.42221	-0.16844	13.26383	-14.73353
1	1	157	-33.40096	-0.20519	13.30232	-20.63580
1	1	158	-38.67574	-0.24801	13.46669	-26.69381
1	1	159	-43.52538	-0.31780	13.68404	-32.34364
1	1	160	-45.78952	-0.38981	13.83425	-37.36276

Figure 2.48
Example of SPUR output when print switch IP3 is set equal to 2. The output for this figure starts on day 140. See the text for a description of the variables shown here.

1	1	140	1.35906	8.80283	4.32143
1	1	141	1.19155	8.71497	4.34700
1	1	142	1.05012	8.62645	4.35111
1	1	143	3.05724	9.65763	4.45249
1	1	144	3.11273	9.57021	4.53847
1	1	145	2.67256	9.41455	4.60337
1	1	146	2.33990	9.27699	4.65178
1	1	147	1.94823	9.13553	4.68577
1	1	148	1.69742	9.01664	4.70905
1	1	149	1.50988	8.89917	4.72320
1	1	150	1.39648	8.79722	4.73016
1	1	151	1.29857	8.71003	4.72996
1	1	152	1.15664	8.62139	4.71120
1	1	153	1.00888	8.52731	4.69192
1	1	154	0.91342	8.37526	4.67132
1	1	155	0.87080	8.23465	4.64997
1	1	156	0.84387	8.09956	4.62824
1	1	157	0.81042	7.87209	4.60541
1	1	158	0.79347	7.65964	4.58216
1	1	159	0.78031	7.39032	4.55850
1	1	160	0.77478	7.17562	4.53281

Figure 2.49
Example of SPUR output when print switch IP3 is set equal to 3. Only output from day 140 through day 160 is shown. See the text for a description of the variables shown.

basis. An example for this report is shown in figure 2.50.

When IP4 is given a value of 2, the output from the plant carbon model is the same as when the switch is set to 1. Additionally, the following variables are printed to LUN 24: the summed net photosynthesis, the summed nighttime respiration, summed root respiration, summed translocation from roots to shoots, summed translocation from shoots to roots, summed root mortality, summed effect of temperature on decomposition, and summed effect of moisture on decomposition. These variables are shown in report form on a per-species, per-site basis. They are printed at the end of every simulated year. An example of this report is shown in figure 2.51.

Some users may wish to view or plot, on a daily basis, a selected few of the variables which are summed and printed when IP4 = 1 or IP4 = 2. To facilitate doing so, the code will print the variables listed below on a daily basis to separate logical unit numbers when IP4 is set to 3. The user is again cautioned to be sure that his or her machine has enough storage and allows multiple logical unit devices to be allocated during one job. This option for IP4 does not produce a report. The variables are not identified beyond the device number to which they are written, so care must be exercised to keep the files separate. The variables are written on one record per simulated day, with a value on each record for each plant species simulated. The format is year, site, day, and then the variable of interest. The variables and the device numbers are translocation from roots to shoots, 26, in grams per square meter; translocation from shoots to roots, 28, in grams per square meter; net photosynthesis, 30, in grams per square meter; effect of moisture on photosynthesis, 32; effect of temperature on photosynthesis, 34; effect of soil nitrogen concentration on photosynthesis, 34; effect of soil temperature on decomposition (this variable is by site), 38; and effect of soil moisture on decomposition (this variable is by site), 40. (Since photosynthesis is integrated over the photoperiod using eight increments, the value for the effect of temperature on photosynthesis printed here is the sum of the ETP values divided by the number of intervals. It may be interpreted as the average effect of temperature on photosynthesis during the photoperiod. Refer to the plant-component documentation for further information.) An example of this output format is shown in figure 2.52.

The output option of switch IP4 set to the value of 4 requires that the user consult the plant-component documentation to fully understand what information this option provides. The carbon submodel of the plant component of SPUR is made up of four compartments per simulated plant species that maintain the individual species identity. The carbon submodel also has three compartments which do not show species identity but show the sum of the contributions from all species for a particular site. This information is written to a file which is formally opened (if IP4 = 4) in the main program and is called CARBON.DAT the LUN for which is 12. The information written to this file is in grams per square meter. That information is site, species number, standing green biomass, live root biomass, propagule biomass, and standing dead biomass. The three compartments without species identity which are written on a per-site basis are dead root biomass, litter biomass, and organic matter biomass. A fourth compartment is also printed which is soil inorganic-nitrogen concentration. These last four variables appear on the same line of output as the information for species one. An example is shown in figure 2.53.

If IP4 is set to a value greater than 4 (maximum of 99), the same information is printed to CARBON.DAT as when it is set to 4, but the output will be on days which are multiples of the value for the print switch. So, if the switch is set to 5, output will be written to CARBON.DAT on day 5, 10, 15, and so on.

Print Switch IP5

This switch controls the writing of variables from the plant component nitrogen submodel. If it is set to zero, no plant nitrogen information will be written.

When the value of IP5 is set to 1, selected plant model nitrogen variables are written in report form to device 42 on a per-site basis at the end of the simulation year. The variables written are peak nitrogen-to-carbon (N/C) ratio, the date for peak N/C, the summed mineralized nitrogen in grams per square meter, the summed fixed nitrogen (from precipitation events) in grams per square meter, the summed effect of moisture on nitrogen uptake,

FOR SIMULATION YEAR 1					
FOR SITE NUMBER 1					
PEAK STANDING CROP (G/M**2)	0.370E+02	0.129E+02	0.157E+01	0.119E+02	0.166E+02
DATE FOR PEAK STANDING CROP	172.000	169.000	171.000	168.000	168.000
SUMMED SHOOT DEATH	0.441E+02	0.134E+02	0.545E+00	0.120E+02	0.174E+02
SUMMED CARBON ASSIMILATION	0.203E+03	0.926E+02	0.178E+01	0.303E+02	0.591E+02
SUMMED EMP	0.285E+03	0.279E+03	0.283E+03	0.270E+03	0.277E+03

Figure 2.50
Example of SPUR output when print switch IP4 is set equal to 1.

FOR SIMULATION YEAR 1					
FOR SITE NUMBER 1					
PEAK STANDING CROP (G/M**2)	0.370E+02	0.129E+02	0.157E+01	0.119E+02	0.166E+02
DATE FOR PEAK STANDING CROP	172.000	169.000	171.000	168.000	168.000
SUMMED SHOOT DEATH	0.441E+02	0.134E+02	0.545E+00	0.120E+02	0.174E+02
SUMMED CARBON ASSIMILATION	0.203E+03	0.926E+02	0.178E+01	0.303E+02	0.591E+02
SUMMED EMP	0.285E+03	0.279E+03	0.283E+03	0.270E+03	0.277E+03
SUMMED PHOTOSYNTHESIS	0.205E+03	0.954E+02	0.180E+01	0.305E+02	0.596E+02
SUMMED NIGHTTIME RESPIRATION	0.176E+01	0.272E+01	0.207E-01	0.180E+00	0.453E+00
SUMMED ROOT RESPIRATION	0.745E+02	0.391E+02	0.308E+01	0.309E+01	0.159E+02
SUMMED TRANS. SHOOT TO ROOT	0.160E+03	0.800E+02	0.296E-01	0.170E+02	0.443E+02
SUMMED TRANS. ROOT TO SHOOT	0.508E+01	0.410E+01	0.207E+00	0.148E+01	0.358E+01
SUMMED ROOT MORTALITY	0.480E+02	0.491E+01	0.209E+01	0.588E+00	0.439E+00
SUMMED ETD	0.817E+02				
SUMMED EMD	0.207E+03				

Figure 2.51
Example of SPUR output when print switch IP4 is set equal to 2.

the summed effect of temperature on nitrogen uptake, and the summed effect of moisture on denitrification. See figure 2.54 for an example of the report produced by this option.

If IP5 is set to a value of 2, the program will write daily values for selected variables to specific LUN's. The format is simulation year, site, day, and then, the variable of interest. The variables and the logical unit numbers to which they are written are effect of moisture on nitrogen uptake, 44; effect of temperature on nitrogen uptake, 46; nitrogen fixed from the atmosphere in grams per square meter, 48; effect of moisture on denitrification, 50; and mineralized nitrogen in grams per square meter, 52. All these variables are written on a per-site basis with the exception of the effect of temperature on nitrogen uptake which is written on a per-species per-site basis. Figure 2.55 is an example of one of these files as it is produced with this option.

The output option of switch IP5 set to the value of 3 requires that the user consult the plant-component documentation to fully understand what information this option provides. The nitrogen submodel of the plant component of SPUR is made up of four compartments per simulated plant species which maintain the individual species identity. This option, however, shows information from only two of these compartments. The nitrogen submodel also has four compartments which do not show species identity but show the sum of the contributions from all species for a particular site. This information is written to a file which is formally opened (if IP5 = 3) in the main program and is called NITRO.DAT the LUN for which is 14. The information written to this file has the units grams per square meter, unless the variable is a ratio. The information is site, species number, nitrogen in the standing green biomass, the nitrogen-to-carbon ratio (N/C) of the standing green biomass, the nitrogen in the live roots, and the N/C of the live roots. The four compartments without species identity which are written on a per-site basis are dead-root nitrogen concentration, litter nitrogen concentration, organic matter nitrogen concentration, and soil inorganic-nitrogen concentration, all in grams per square meter. These last four variables appear on the same line as the information for species one.

If IP5 is set to a value greater than 3 (maximum of 99), the same information is printed to NITRO.DAT as when it is set to 3, but the output will be on days which are multiples of the value for the print switch. So, if the switch is set to 5, output will be written to NITRO.DAT on day 5, 10, 15, and so on.

1	1	155	1.00000	1.00000	1.00000	1.00000	1.00000
1	1	156	1.00000	1.00000	1.00000	1.00000	1.00000
1	1	157	1.00000	1.00000	1.00000	1.00000	1.00000
1	1	158	1.00000	1.00000	1.00000	1.00000	1.00000
1	1	159	1.00000	1.00000	1.00000	1.00000	1.00000
1	1	160	1.00000	1.00000	1.00000	1.00000	1.00000
1	1	161	1.00000	1.00000	1.00000	1.00000	1.00000
1	1	162	1.00000	1.00000	1.00000	0.99999	1.00000
1	1	163	1.00000	1.00000	1.00000	0.99997	1.00000
1	1	164	1.00000	1.00000	1.00000	0.99985	1.00000
1	1	165	1.00000	1.00000	1.00000	0.99951	0.99999
1	1	166	1.00000	0.99998	1.00000	0.99827	0.99995
1	1	167	1.00000	0.99953	0.99999	0.98349	0.99883
1	1	168	1.00000	0.98305	0.99939	0.79772	0.95653
1	1	169	0.99997	0.71674	0.98003	0.27029	0.47613
1	1	170	0.99705	0.11036	0.62680	0.03660	0.04055
1	1	171	0.89164	0.01175	0.10847	0.00642	0.00387
1	1	172	0.35998	0.00218	0.01793	0.00179	0.00069
1	1	173	0.07008	0.00061	0.00439	0.00069	0.00019
1	1	174	0.02057	0.00027	0.00178	0.00037	0.00008
1	1	175	0.00668	0.00013	0.00080	0.00022	0.00004
1	1	176	0.00361	0.00009	0.00052	0.00016	0.00003
1	1	177	0.00218	0.00007	0.00036	0.00013	0.00002
1	1	178	0.00165	0.00005	0.00030	0.00011	0.00002
1	1	179	0.00136	0.00005	0.00026	0.00010	0.00001
1	1	180	0.00124	0.00005	0.00024	0.00010	0.00001

Figure 2.52
Example of SPUR output when print switch IP4 is set equal to 3. This file was written to LUN 32 and only day 155 through day 180 are shown. The effect of moisture on photosynthesis (EMP) for each day for each of the five plant species simulated is shown.

Print Switch IP6

The print flag IP6 controls output that relates to the steer growth and the animal/plant interface components. If IP6 is set to zero, none of this output will be produced. Use of IP6 is valid only if the SPUR model has been told that steers will be grazing during the experiment. If IP6 has been assigned a value other than zero, but the number of steers (NUM) is read as zero, the program code will produce the following message, written to the SUMARY.DAT file:

PRINT SWITCH IP6 RESET TO ZERO

If IP6 is the only print switch turned on for this particular simulation experiment and it is reset to zero, the code will also write:

W A R N I N G - NO PRINT SWITCH HAS BEEN TURNED ON

to the SUMARY.DAT file.

If IP6 is given a value of 1, selected livestock-component variables are written to device 54 in report form. The variables are the total weight gain (kg) for a single average steer for the grazing season, and the summed live and dead dry matter, in kilogram per hectare, harvested for all forage species.

A value of 2 for IP6 will produce, on LUN 56, daily grazing-season output of each forage class (live and dead) for each forage species that is harvested. The units are in grams per square meter. The values reflect all harvested forage, no matter if removal is by steers or wildlife or both.

If IP6 is assigned a value of 3, daily information will be output to device 58. That information is simulation year, simulation day, percent crude protein of all forage (live and dead) demanded by the livestock, the digestible dry matter of forage consumed by livestock, the amount of forage demanded by all steers, and the weight of an average steer. This information is written only for the simulated grazing season.

If IP6 is given a value of 4, the program code will write daily information to LUN 60. That information is one record per day and is the simulation year, site, day, and forage species harvest, both live and dead. This information is written only for the grazing season.

Print Switch IP7

The print flag IP7 controls output that relates to

1	1	158	6.847	237.287	0.000	5.120	598.419	160.946	1817.149	0.000
1	2	158	11.801	118.209	0.000	0.244				
1	3	158	0.080	34.005	0.000	0.003				
1	4	158	11.314	45.328	0.000	0.496				
1	5	158	15.989	79.988	0.000	23.478				
1	1	159	10.504	236.325	0.000	5.117	599.256	161.050	1817.153	0.000
1	2	159	11.932	119.517	0.000	0.277				
1	3	159	0.104	33.952	0.000	0.003				
1	4	159	11.406	45.694	0.000	0.531				
1	5	159	16.076	80.423	0.000	23.462				
1	1	160	15.369	235.413	0.000	5.131	600.032	161.149	1817.157	0.000
1	2	160	12.060	120.779	0.000	0.312				
1	3	160	0.119	33.900	0.000	0.004				
1	4	160	11.491	46.026	0.000	0.568				
1	5	160	16.156	80.817	0.000	23.448				
1	1	161	23.523	235.380	0.000	5.170	600.597	161.234	1817.163	0.000
1	2	161	12.181	122.004	0.000	0.348				
1	3	161	0.145	33.852	0.000	0.004				
1	4	161	11.564	46.323	0.000	0.608				
1	5	161	16.228	81.179	0.000	23.439				
1	1	162	24.690	247.058	0.000	5.233	601.169	161.337	1817.169	0.000
1	2	162	12.296	123.146	0.000	0.383				
1	3	162	0.181	33.804	0.000	0.005				
1	4	162	11.628	46.578	0.000	0.645				
1	5	162	16.292	81.502	0.000	23.431				
1	1	163	25.845	258.603	0.000	5.260	601.811	161.514	1817.174	0.002
1	2	163	12.413	124.316	0.000	0.413				
1	3	163	0.229	33.756	0.000	0.005				
1	4	163	11.690	46.826	0.000	0.667				
1	5	163	16.353	81.808	0.000	23.416				
1	1	164	26.886	269.012	0.000	5.241	602.343	161.758	1817.180	0.005
1	2	164	12.534	125.525	0.000	0.437				
1	3	164	0.284	33.710	0.000	0.006				
1	4	164	11.751	47.068	0.000	0.674				
1	5	164	16.410	82.093	0.000	23.403				
1	1	165	28.187	282.024	0.000	5.167	602.771	162.078	1817.188	0.009
1	2	165	12.634	126.532	0.000	0.454				
1	3	165	0.374	33.666	0.000	0.007				
1	4	165	11.794	47.241	0.000	0.666				
1	5	165	16.457	82.328	0.000	23.392				

Figure 2.53
Example of SPUR output when print switch IP4 is set equal to 4. Five plant species on one site are simulated. Only day 158 through 165 of the simulation are shown. See the text for a description of the variables presented.

the wildlife and the animal/plant interface components. If IP7 is set to zero, none of this output will be produced. Use of IP7 is valid only if the SPUR model has been told that one or more wildlife species (to a maximum of ten) will be grazing during the experiment. If IP7 has been assigned a value other than zero, but the number of wildlife species (NWS) is read as zero, the program code will produce the following message, written to the SUMARY.DAT file:

PRINT SWITCH IP7 RESET TO ZERO

If IP7 is the only print switch turned on for this particular simulation experiment and it is reset to zero, the code will also write:

W A R N I N G - NO PRINT SWITCH
HAS BEEN TURNED ON

to the SUMARY.DAT file.

If IP7 is given the value of 1, the program code writes the following information, on a daily basis, to LUN 62: the simulation year, site, day, and total harvested forage (live and dead) by forage species per site. The user should be aware that if he is simulating a large number of wildlife species as well as a large number of sites, this option will produce a large number of output lines written to the device and also produce a consequent large number of lines when the file is printed to hardcopy.

FOR SIMULATION YEAR 1					
FOR SITE NUMBER 1					
PEAK N:C BY SPECIES	0.308E-01	0.304E-01	0.303E-01	0.300E-01	0.302E-01
DATE PEAK N:C BY SPECIES	154.000	106.000	156.000	106.000	106.000
SUMMED ETNU BY SPECIES	0.954E+02	0.147E+03	0.954E+02	0.141E+03	0.146E+03
SUMMED EMNU	0.256E+03				
SUMMED EMD	0.275E+03				
SUMMED MINERAL NITROGEN	0.136E+01				
SUMMED FIXED NITROGEN	0.311E+00				

Figure 2.54
Example of SPUR output when print switch IP5 is set equal to 1.

1	1	140	0.00486
1	1	141	0.01550
1	1	142	0.00000
1	1	143	0.00226
1	1	144	0.01410
1	1	145	0.02638
1	1	146	0.02696
1	1	147	0.02691
1	1	148	0.03432
1	1	149	0.02128
1	1	150	0.02888
1	1	151	0.01875
1	1	152	0.02136
1	1	153	0.01226
1	1	154	0.00611
1	1	155	0.00095
1	1	156	0.00134
1	1	157	0.00027
1	1	158	0.00034
1	1	159	0.00020
1	1	160	0.00021
1	1	161	0.00031
1	1	162	0.00028
1	1	163	0.00025
1	1	164	0.00032
1	1	165	0.00039

Figure 2.55
Example of SPUR output when print switch IP5 is set equal to 2. This information is mineralized nitrogen in grams per square meter and was written to LUN 52. Only day 140 through day 165 are shown.

3. USER GUIDE FOR THE BASIN-SCALE VERSION

E.P. Springer, J.W. Skiles

INTRODUCTION

This guide is intended to provide users with the necessary inputs and their formats for operation of the basin-scale version of the SPUR model. The inputs for the plant and animal components are essentially the same as for the field-scale version of the model (see chapter 2), but they are given here for complete reference. A prudent user will read both this chapter and the previous chapter on the field-scale version of the SPUR model. We also encourage users to study and run the example problems so they will have a better understanding of model operation and file structure and so that they will gain confidence in model use.

The basin-scale version of SPUR is designed for watershed-scale analyses of range management practices. The basic management unit is a watershed with at least one channel. Upland areas (nonchannel) can be divided into fields to allow spatial representation of different soils, management practices, inputs, and so forth, but these fields must be connected to a channel. Therefore, the subdivision of a watershed is parallel rather than perpendicular to a channel. This location results in grazing and plant production being simulated uniformly over the field regardless of slope position. The user should be aware that the resolution of the plant and animal components that was attained in the field-scale version of SPUR by using sites is lost in the basin-scale version.

PROGRAM ORGANIZATION

The basin-scale version of the SPUR program is composed of 48 modules, where a module is a program, subroutine subprogram, or function subprogram. Table 3.1 lists the program and subprograms in the order in which they occur in the computer code. A brief explanation of their function is also presented. Note that function subprograms are included with the subroutine subprograms. Table 3.2 presents the hierarchy of the main program and subprograms.

The flow of the basin-scale main program is much the same as the field-scale version of the model. Figure 3.1 is a display of the loop control of the basin-scale model.

Flowcharts

To aid the user in understanding SPUR program execution, 48 flowcharts are included in this chapter. Figure 2.2 defines the symbols used in the flowcharts and figures 3.2 through 3.49 represent each of the basin-scale SPUR program modules, including a chart for the COMBLK module. Only major calculations or decisions are shown in the flowcharts; bookkeeping and zeroing accumulators, for instance, are generally not shown.

FILE STRUCTURE

Operation of the basin-scale SPUR program calls for the opening of six files. Four of these files are for input, one is output, and the remaining file is a scratch file. Logical unit numbers (LUN's) have been assigned in the following manner; LUN 3 is for the animal input file; LUN 4 is for the climate input file; LUN 8 is for the hydrology input file; and LUN 9 is for the plant-input file. The user is prompted for the file name by the following statement:

ENTER FILE NAME FOR ANIMAL DATA

The user enters the data file name containing the data for the animal component. The program then writes:

ENTER FILE NAME FOR CLIMATIC DATA

then

ENTER FILE NAME FOR HYDROLOGY DATA

then

ENTER FILE NAME FOR PLANT DATA

The user responds with the appropriate file names after each request.

These files have remained separated to assist users in finding and changing parameters and initial conditions of interest in specific model components. The main output file is written to LUN 16 and is called SUMARY.DAT. Also, a scratch file is assigned to LUN 10. Logical units 5 and 6 are reserved for interaction with the user.

A comment is required on the scratch file. For greater efficiency in input/output operations and reduced storage overhead, this file is unformatted. The user should check his computing system's file-handling conventions to make sure this file is initialized and accessed correctly.

Discretizing Watersheds

Before constructing an input file for the basin-scale version of SPUR, the subject watershed must be broken into a system of fields, channels, and if present, ponds. Examples of this procedure as well as some basic rules are presented in this section. Data files for two watersheds presented in this discussion are included in the sample problem sets in Part II, chapter 12.

Users must consider the increased computer time required when dividing a watershed into a larger number of fields and/or channels. Prudent judgment should be exercised when watersheds are discretized for simulation.

Table 3.1
Module number, module name, and module description of the main program and subprograms in the basin-scale version of SPUR

Number	Name	Description
01	BSVPI	Main calling program, calls initializing subprograms, contains year, month, and day loops, and sums results for reporting.
02	COMBLK	A block common segment which contains values in data statements for the variables passed in the common blocks; the values are assigned at compile time.
03	ADPL	Subprogram to calculate snow areal depletion curve for each field.
04	AESC19	Subprogram to adjust areal snow cover based on current melt or accumulation.
05	ALBEDO	Subprogram to determine surface albedo for the day.
06	ANIMAL	Subprogram for control of animal routines.
07	ATANF	Subprogram for arc tangent function referenced by plant routines.
08	BELL	Subprogram for bell-shaped function referenced by plant routines.
09	CHNSED	Subprogram for calculating sediment yield from a channel.
10	CLIM	Subprogram to read weather data and calculate potential evapotranspiration for each field.
11	CRACK	Subprogram to compute crack flow.
12	DAYSUM	Subprogram for daily summary for later writing of monthly and annual reports; the storm-day report is written here.
13	ERR	Subprogram containing error codes for input routines called from those routines. (See ch. 9 for a list of error codes.)
14	EVAPR	Subprogram to compute evapotranspiration.
15	FLDHYD	Subprogram to control daily soil-water balance routines for each field and calculate surface runoff volume and peak flow rate.
16	GROW	Subprogram to calculate steer growth and forage requirements.
17	HYP	Subprogram for hyperbolic function referenced by plant routines.
18	IOSET	Subprogram for opening file; input, output, and scratch files are opened in this routine.
19	LINE	Subprogram to control output paging, called from several places in the program depending on the print switches used.
20	LVSTK	Subprogram for control of steer growth and forage consumption.

Table 3.1--Continued
Module number, module name, and module description of the main program and subprograms in the basin-scale version of SPUR

Number	Name	Description
21	MELT19	Subprogram to calculate melt for nonrain periods and 100 percent snow cover.
22	MUSLE	Subprogram to calculate upland soil loss using the Modified Universal Soil Loss Equation (MUSLE).
23	NDPM	Subprogram to determine number of days in the month.
24	NITE	Subprogram to determine nitrogen dynamics in plants and soils.
25	NTRFC	Subprogram to determine the amount of forage consumed. (This is the plant/animal iNTeRFaCe.)
26	PACK19	Subprogram to calculate snow accumulation and melt.
27	PERC	Subprogram to compute percolation when water content is greater than field capacity.
28	PEXP	Subprogram to calculate peak photosynthesis rate for existing conditions for the day.
29	PHOPER	Subprogram to calculate daily photoperiod.
30	PHOTO	Subprogram to determine daily photosynthesis.
31	PLANT	Subprogram for control of plant routines.
32	PLGRO	Subprogram which calculates biomass dynamics of plant species and fields.
33	PONDF	Subprogram to calculate pond-water balance.
34	ROUT19	Subprogram to route excess water through the snowpack.
35	SOIL	Subprogram to compute current soil-water status.
36	SOILC	Subprogram to calculate soil-water content versus soil-water tension curve and lower soil water content boundary.
37	SOILM	Subprogram to calculate soil-water tension in the top soil layer and the wettest layer in the root zone for each field.
38	SOLADJ	Subprogram to adjust incoming solar radiation for slope and aspect of a field.
39	SSFLOW	Subprogram to compute subsurface return flow.
40	TEMPP	Subprogram referenced by plant routines to calculate temperatures.
41	THRESH	Subprogram for threshold function referenced by plant routines.
42	TLAPSE	Subprogram to lapse temperature if elevation of simulation site is different from elevation of site at which temperature is measured. A standard lapse rate of 6.5 °C/1000 m is used.

Table 3.1--Continued
Module number, module name, and module description of the main program and subprograms in the basin-scale version of SPUR

Number	Name	Description
43	TRATE	Subprogram to determine transport rates for suspended and bedload material.
44	USER	Subprogram to initialize hydrology, plant and animal components.
45	WLDLF	Subprogram to calculate demand for forage by wildlife species present.
46	YRSUM	Subprogram for writing monthly and annual reports.
47	ZERO	Subprogram to zero forage-supply arrays.
48	ZERO19	Subprogram to zero snow accumulation values when snow water is depleted.

As mentioned, upland watershed elements are known as fields and fields are connected to channels. Channels must have at least one field assigned to them or an execution error will result. Fields are termed either upland or lateral. An upland field is at the head of a channel and a lateral field, as its name implies, lies alongside a channel. A maximum of two upstream channels may feed into a single downstream channel. Ponds are located at a channel outlet, so a pond in the center of a watershed starts a new channel.

In the following discussion three watersheds are presented as examples of how watersheds can be discretized. Figure 3.50 is the Upper Sheep Creek watershed in the Reynolds Creek Experimental Watershed, Owyhee County, Idaho, operated by the USDA-ARS, Northwest Watershed Research Center. It represents an example of the simplest system utilizing all types of fields. The watershed is comprised of two lateral fields, a single upland field, and a single channel. This type of division was prompted by differences in soil characteristics and snow accumulation and melt among the three fields.

Figure 3.51 is the Lucky Hills Watershed located in the Walnut Gulch Experimental Watershed (Cochise County, Arizona) and operated by the USDA-ARS Southwest Rangeland Watershed Research Center. Lucky Hills is an example of a 2-channel watershed. Although a single main channel apparently is present, differences in vegetation and management made the designation of C2 appropriate. The subbasin defined by C2 is composed of two lateral fields and a single upland field. The C1 subbasin is composed of two lateral fields and is fed by C2.

At this point, a comment is required about entering channels and subbasins, basin numbers, and order of execution. Execution should proceed from the upstream end of the watershed towards the outlet. The SPUR model processes subbasins in the order of entry in the input file. Obviously, channels which feed downstream channels should be processed before a downstream channel. The numbers assigned at time of input are for bookkeeping purposes and have nothing to do with execution. So for the Lucky Hills Watershed previously described, subbasin C2 is entered before C1 as is shown in the example problem provided for this watershed.

The final example (Figure 3.52) indicates how a potentially complex watershed is described. The watershed is the Murphy Creek Watershed which is also located in the Reynolds Creek Experimental Watershed and was used in a study of the SPUR hydrology component by Springer et al. (1984). The limitation of the number of channels that can feed a downstream channel (two is the maximum) requires the formation of subbasins (for example, channel numbers 3 and 8 and their adjoining upland areas) which are not physically meaningful. The result is a watershed with 8 channels and 16 fields.

These examples are presented to exhibit some of the major principles used for discretizing a watershed for the basin-scale version of SPUR. By no means should these examples be considered exhaustive. This portion of the input file construction is crucial and users should exercise care when completing this operation.

Hydrology-Component Input File

Table 3.3 lists the variables, their format, and description for each record in the hydrology input file.

Record types 1 to 4 are used only once for each simulation to specify the simulation problem and control execution. Record 1 is the title card. The title may be a maximum length of 80 characters including spaces. Record 2 is the control card.
(text continues on page 217)

Table 3.2
Hierarchy of the calling and called modules in the basin-scale version of SPUR. The numbers correspond to those shown in table 3.1

Level Number	Module	Calls	Called by
LEVEL 0:	1P-BSVPI	... CALLS 9S-CHNSED, 10S-CLIM, 12S-DAYSUM, 13S-ERR, 15S-FLDHYD, 18S-IOSET, 19S-LINE, 22S-MUSLE, 23S-NDPM, 31S-PLANT, 33S-PONDF, 44S-USER, 46S-YRSUM	... CALLED BY NO SUBPROGRAMS
LEVEL 1:	46S-YRSUM	... CALLS 19S-LINE	... CALLED BY 1P-BSVPI
	44S-USER	... CALLS 3S-ADPL, 4S-AESC19, 13S-ERR, 19S-LINE, 36S-SOILC	... CALLED BY 1P-BSVPI
	33S-PONDF	... CALLS NO SUBPROGRAMS	... CALLED BY 1P-BSVPI
	31S-PLANT	... CALLS 6S-ANIMAL, 29F-PHOPER, 32S-PLGRO, 37S-SOILM, 40F-TEMPP	... CALLED BY 1P-BSVPI
	23S-NDPM	... CALLS NO SUBPROGRAMS	... CALLED BY 1P-BSVPI
	22S-MUSLE	... CALLS NO SUBPROGRAMS	... CALLED BY 1P-BSVPI
	18S-IOSET	... CALLS NO SUBPROGRAMS	... CALLED BY 1P-BSVPI
	15S-FLDHYD	... CALLS 26S-PACK19, 35S-SOIL	... CALLED BY 1P-BSVPI
	12S-DAYSUM	... CALLS 19S-LINE	... CALLED BY 1P-BSVPI
	10S-CLIM	... CALLS 5F-ALBEDO, 13S-ERR, 19S-LINE, 38F-SOLADJ, 42F-TLAPSE	... CALLED BY 1P-BSVPI
	9S-CHNSED	... CALLS 43S-TRATE	... CALLED BY 1P-BSVPI
LEVEL 2:	43S-TRATE	... CALLS NO SUBPROGRAMS	... CALLED BY 9S-CHNSED
	42F-TLAPSE	... CALLS NO SUBPROGRAMS	... CALLED BY 10S-CLIM
	38F-SOLADJ	... CALLS NO SUBPROGRAMS	... CALLED BY 10S-CLIM
	5F-ALBEDO	... CALLS NO SUBPROGRAMS	... CALLED BY 10S-CLIM
	35S-SOIL	... CALLS 11S-CRACK, 14S-EVAPR, 27S-PERC, 39S-SSFLOW	... CALLED BY 15S-FLDHYD
	26S-PACK19	... CALLS 4S-AESC19, 21S-MELT19, 34S-ROUT19, 48S-ZERO19	... CALLED BY 15S-FLDHYD
	37S-SOIL	... CALLS NO SUBPROGRAMS	... CALLED BY 31S-PLANT
	32S-PLGRO	... CALLS 7F-ATANF, 8F-BELL, 17F-HYP, 24S-NITE, 30S-PHOTO, 40F-TEMPP, 41F-THRESH	... CALLED BY 31S-PLANT
	29F-PHOPER	... CALLS NO SUBPROGRAMS	... CALLED BY 31S-PLANT
	6S-ANIMAL	... CALLS 20S-LVSTK, 45S-WLDLF	... CALLED BY 31S-PLANT
	36S-SOILC	... CALLS NO SUBPROGRAMS	... CALLED BY 44S-USER
	3S-ADPL	... CALLS NO SUBPROGRAMS	... CALLED BY 44S-USER
	19S-LINE	... CALLS NO SUBPROGRAMS	... CALLED BY 1P-BSVPI, 10S-CLIM, 12S-DAYSUM, 44S-USER, 46S-YRSUM
	13S-ERR	... CALLS NO SUBPROGRAMS	... CALLED BY 1P-BSVPI, 10S-CLIM, 44S-USER
LEVEL 3:	45S-WLDLF	... CALLS 25S-NTRFC	... CALLED BY 6S-ANIMAL
	20S-LVSTK	... CALLS 16S-GROW, 25S-NTRFC	... CALLED BY 6S-ANIMAL
	41F-THRESH	... CALLS NO SUBPROGRAMS	... CALLED BY 32S-PLGRO
	30S-PHOTO	... CALLS 28F-PEXP, 40F-TEMPP	... CALLED BY 32S-PLGRO
	24S-NITE	... CALLS 8F-BELL, 17F-HYP	... CALLED BY 32S-PLGRO
	7F-ATANF	... CALLS NO SUBPROGRAMS	... CALLED BY 32S-PLGRO
	48S-ZERO19	... CALLS NO SUBPROGRAMS	... CALLED BY 26S-PACK19
	34S-ROUT19	... CALLS NO SUBPROGRAMS	... CALLED BY 26S-PACK19
	21S-MELT19	... CALLS NO SUBPROGRAMS	... CALLED BY 26S-PACK19
	39S-SSFLOW	... CALLS NO SUBPROGRAMS	... CALLED BY 35S-SOIL
	27S-PERC	... CALLS NO SUBPROGRAMS	... CALLED BY 35S-SOIL
	14S-EVAPR	... CALLS NO SUBPROGRAMS	... CALLED BY 35S-SOIL
	11S-CRACK	... CALLS NO SUBPROGRAMS	... CALLED BY 35S-SOIL
	4S-AESC19	... CALLS NO SUBPROGRAMS	... CALLED BY 26S-PACK19, 44S-USER
LEVEL 4:	28F-PEXP	... CALLS 8F-BELL	... CALLED BY 30S-PHOTO
	16S-GROW	... CALLS NO SUBPROGRAMS	... CALLED BY 20S-LVSTK
	25S-NTRFC	... CALLS 47S-ZERO	... CALLED BY 20S-LVSTK, 45S-WLDLF
	17F-HYP	... CALLS NO SUBPROGRAMS	... CALLED BY 24S-NITE, 32S-PLGROW
	40F-TEMPP	... CALLS NO SUBPROGRAMS	... CALLED BY 30S-PHOTO, 31S-PLANT, 32S-PLGRO
LEVEL 5:	47S-ZERO	... CALLS NO SUBPROGRAMS	... CALLED BY 25S-NTRFC
	8F-BELL	... CALLS NO SUBPROGRAMS	... CALLED BY 24S-NITE, 28F-PEXP, 32S-PLGRO

F represents a function subprogram, P represents the main program,
S represents a subroutine subprogram.

```
begin YEAR Loop
  begin MONTH Loop
     call NDPM
    begin DAY Loop
       call CLIM
       call PLANT
      begin CHANNEL Loop
        begin FIELD Loop
           call FLDHYD
           call MUSLE
        end FIELD Loop
         call CHNSED
         call PONDF
      end CHANNEL Loop
       call DAYSUM
    end DAY Loop
  end MONTH Loop
end YEAR Loop
```

Figure 3.1
Basin-scale version of SPUR: Main program control loops.

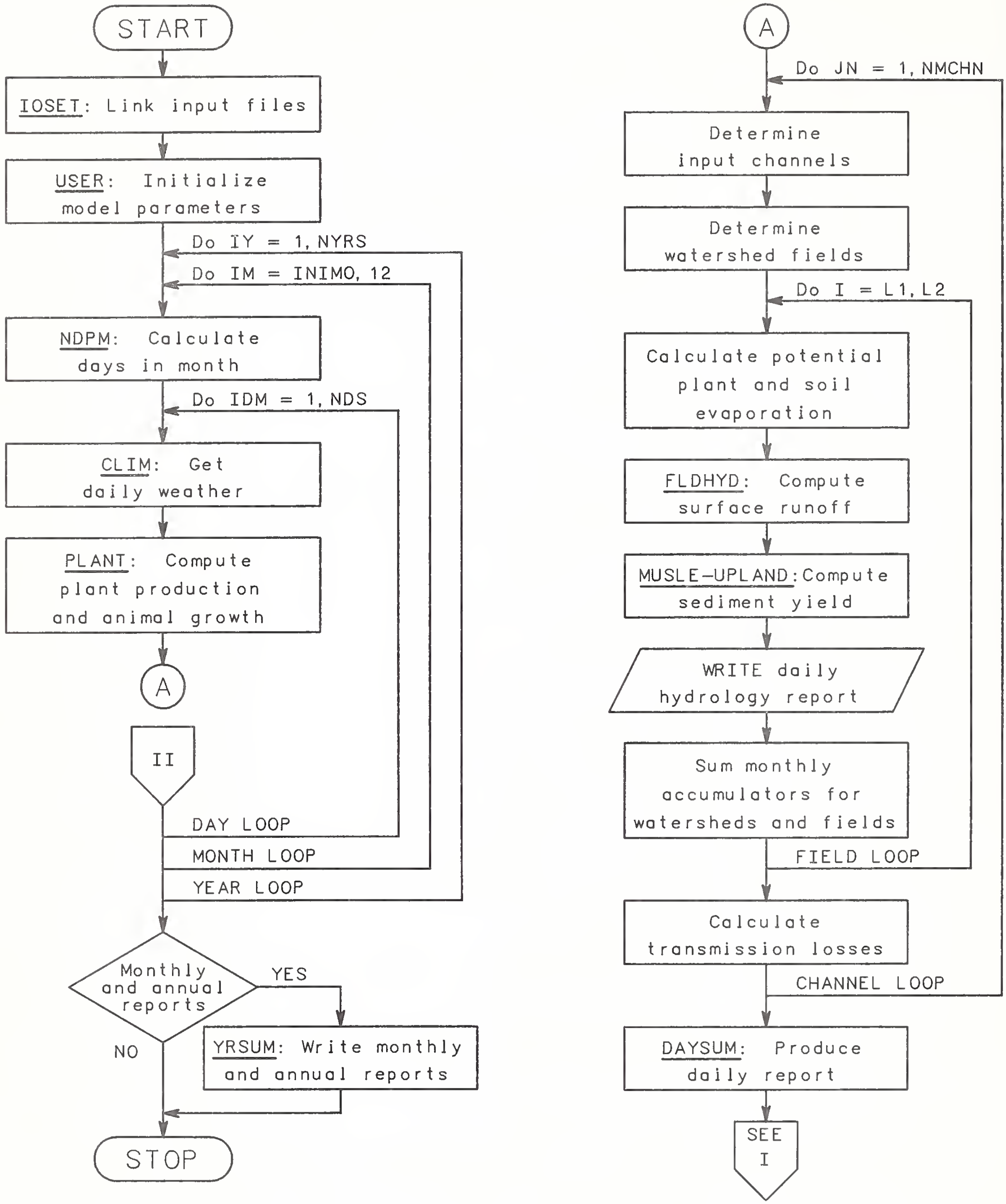


Figure 3.2
Program BSVPI: SPUR basin-scale version phase I.

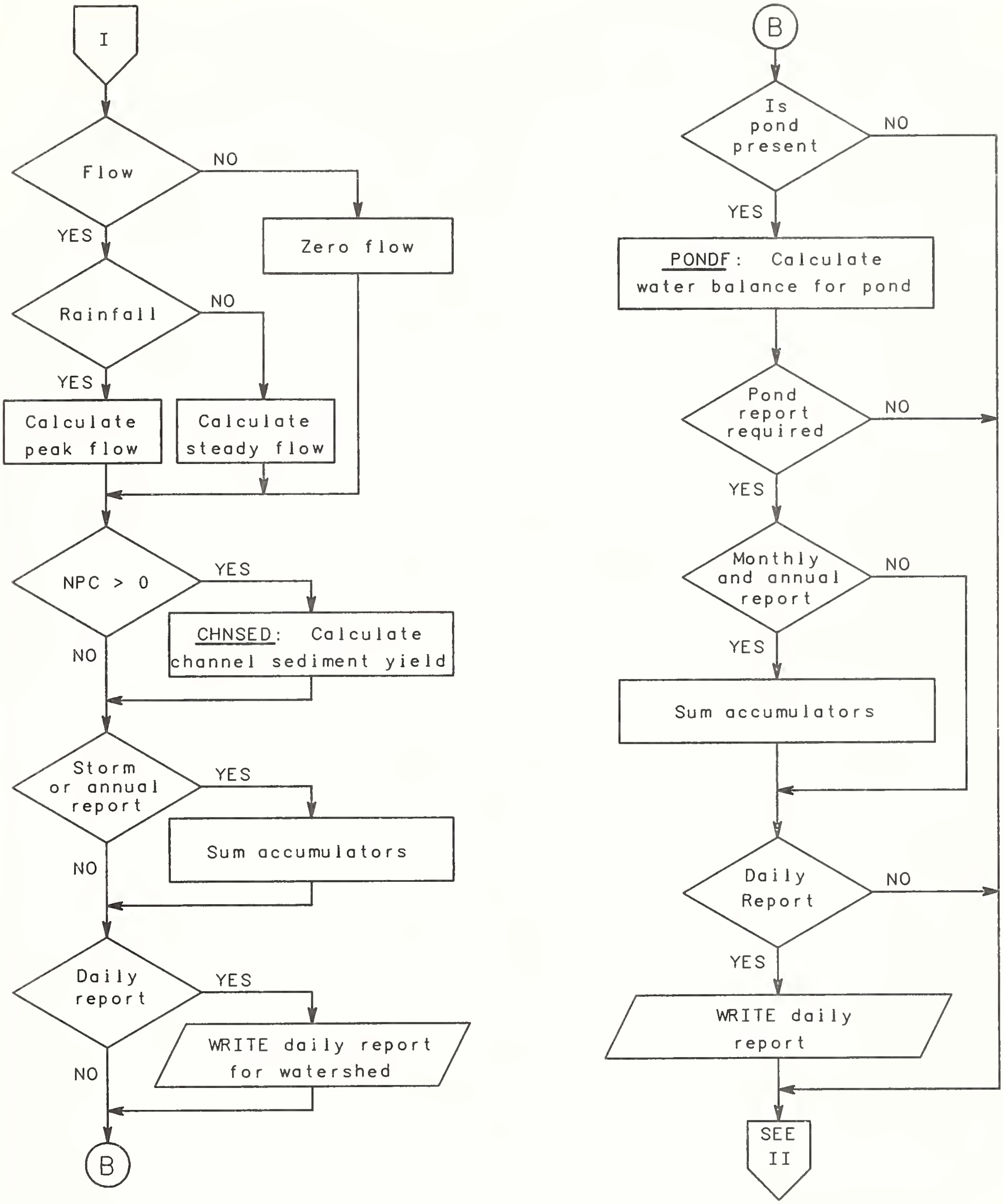


Figure 3.2--Continued
Program BSVPI: SPUR basin-scale version phase I.

(Initializes variables passed in labeled COMMON blocks; values assigned at compile-time).

Figure 3.3
COMBLK: Initializes variables passed in labeled COMMON blocks.

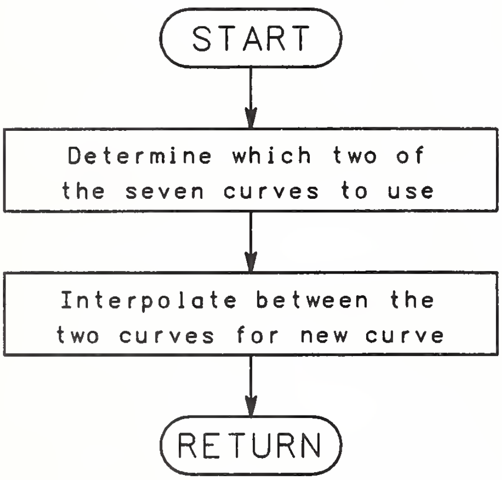


Figure 3.4
Subroutine ADPL: Determine the areal depletion curve.

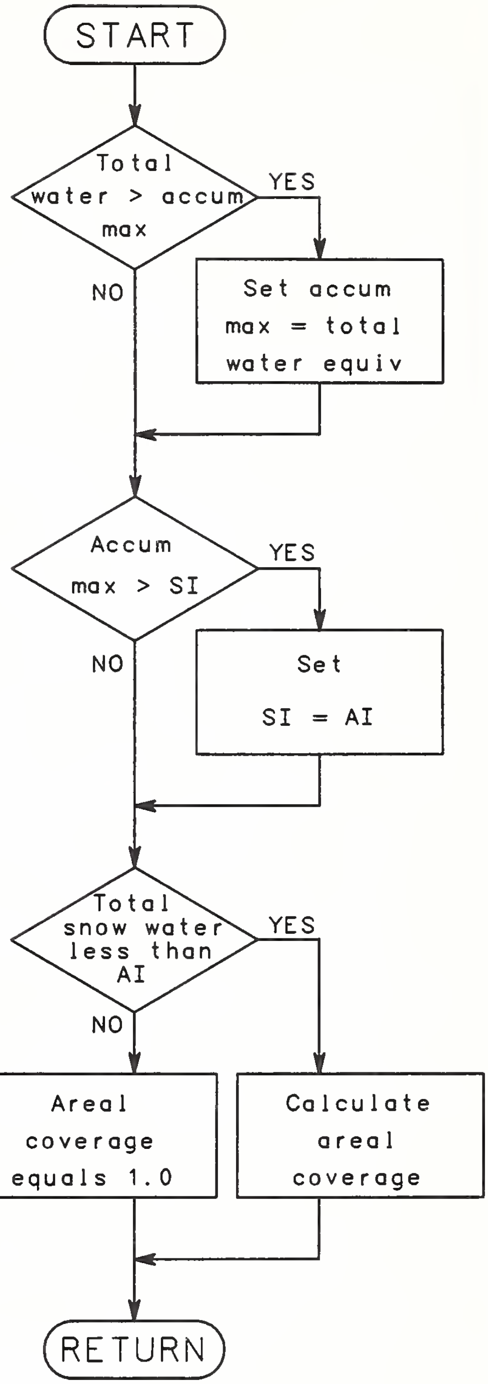


Figure 3.5
Subroutine AESC19: Compute the areal extent of snow cover.

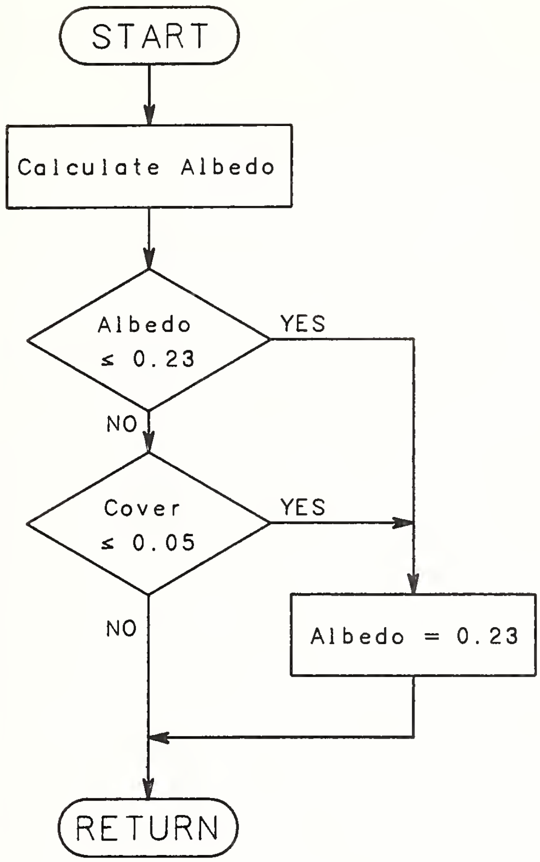


Figure 3.6
Function ALBEDO: Calculate the albedo.

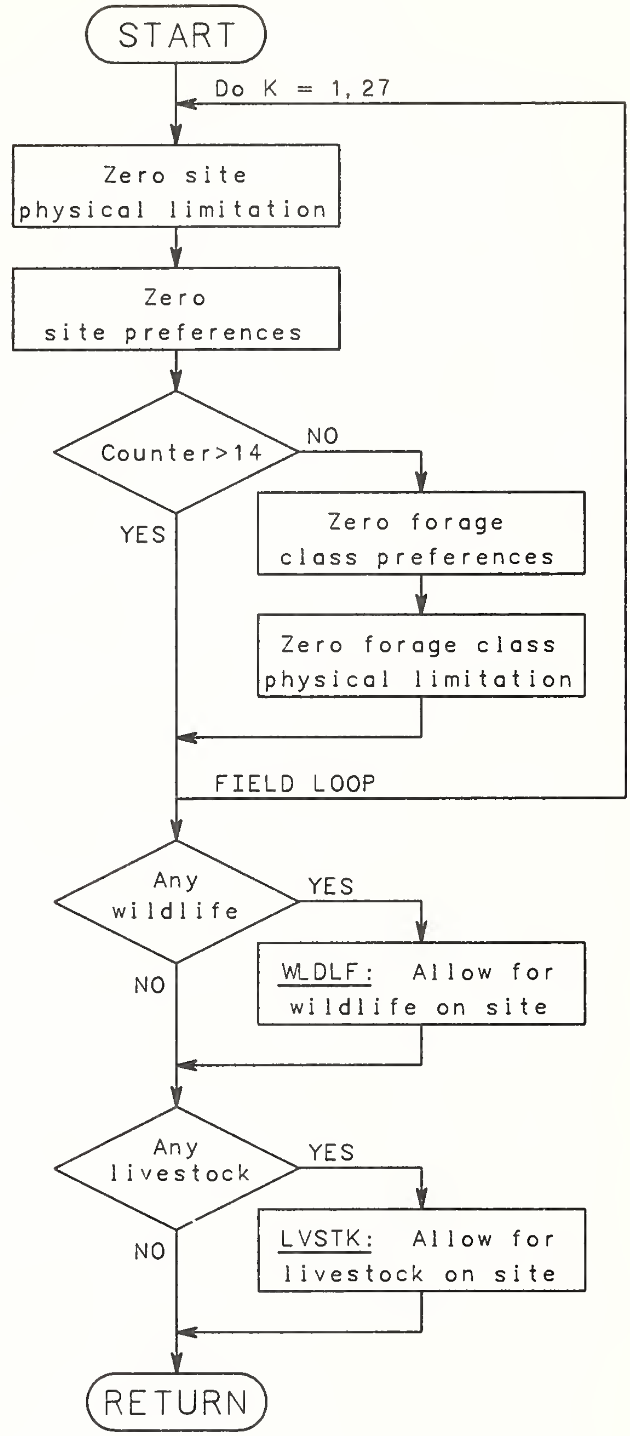


Figure 3.7
Subroutine ANIMAL: Controls calls to wildlife and livestock routines.

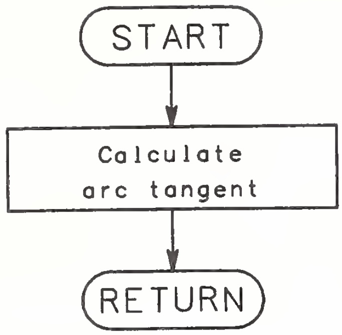


Figure 3.8
Function ATANF:
Calculate arc
tangent.

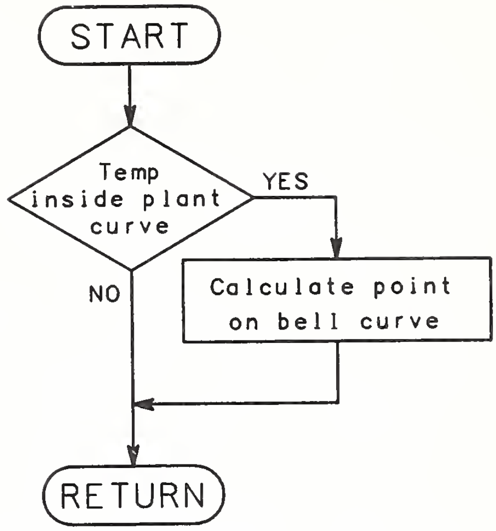


Figure 3.9
Function BELL:
Calculate position
on the plant bell
curve.

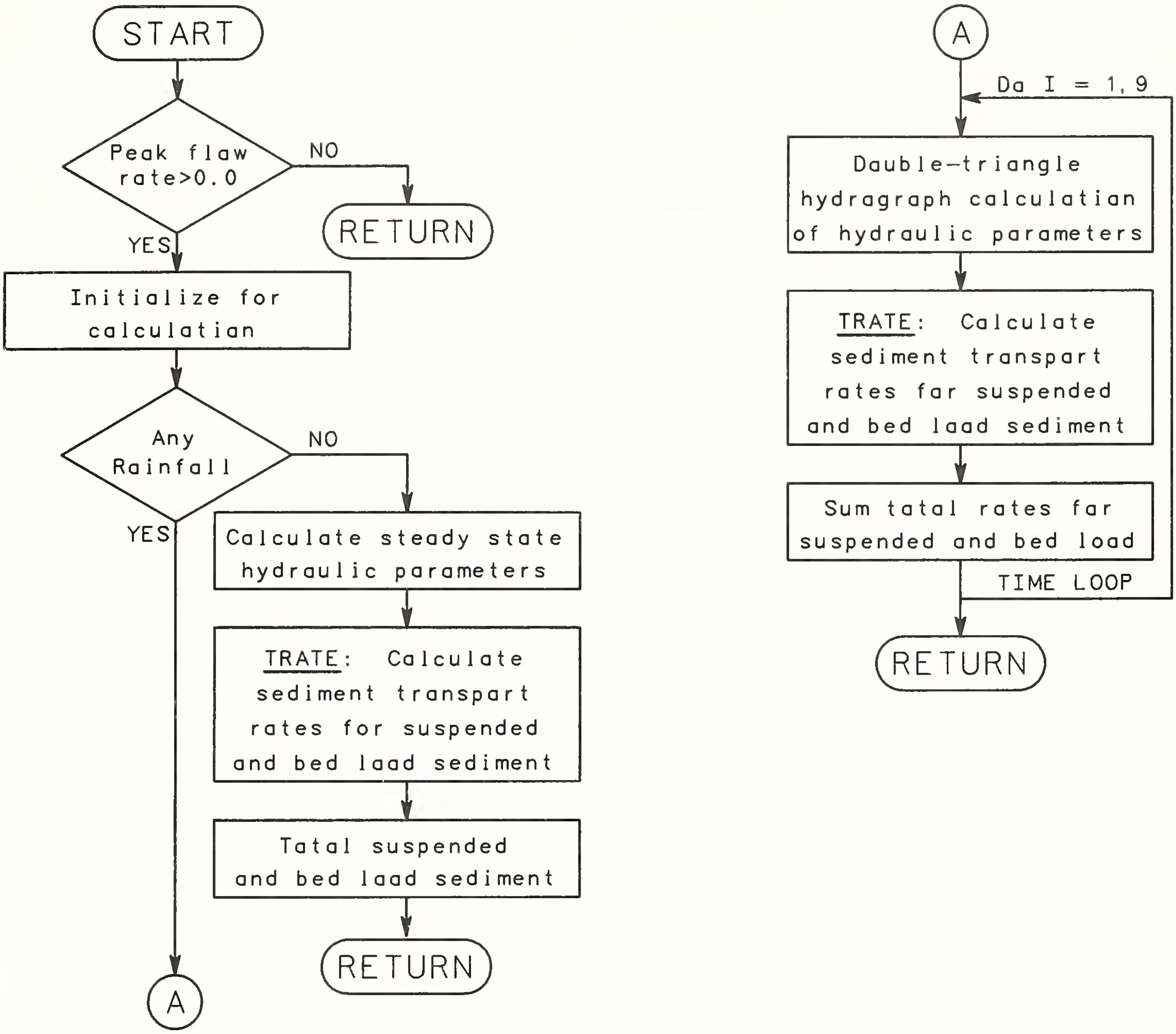
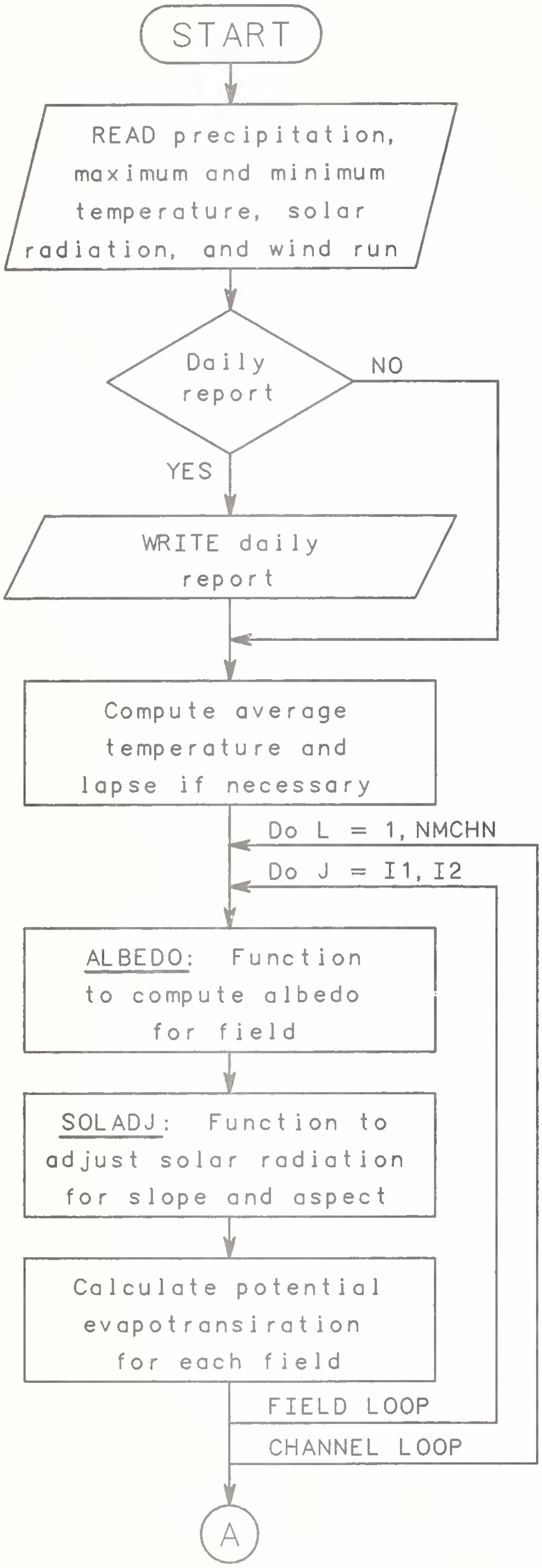


Figure 3.10
Subroutine CHNSED: Compute sediment yield from a channel.



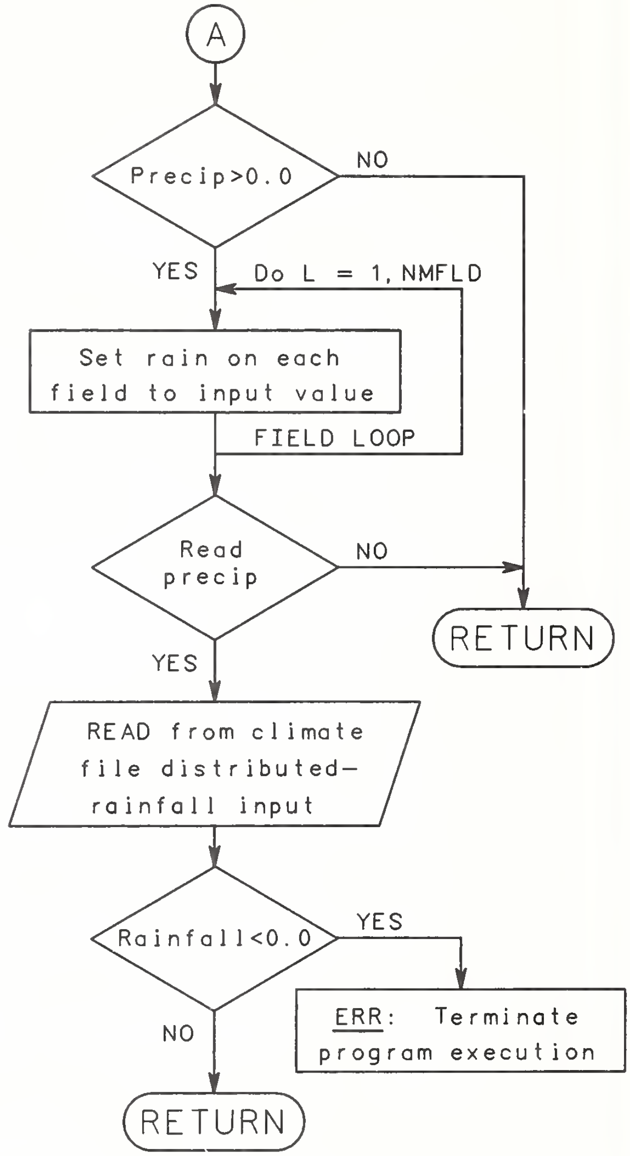


Figure 3.11
Subroutine CLIM: Determine climatic conditions.

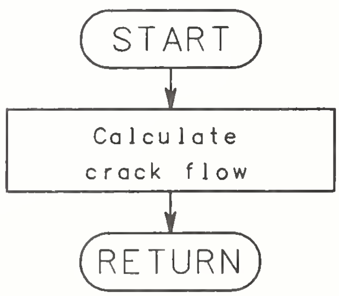


Figure 3.12
Subroutine CRACK: Calculate water flow through cracks.

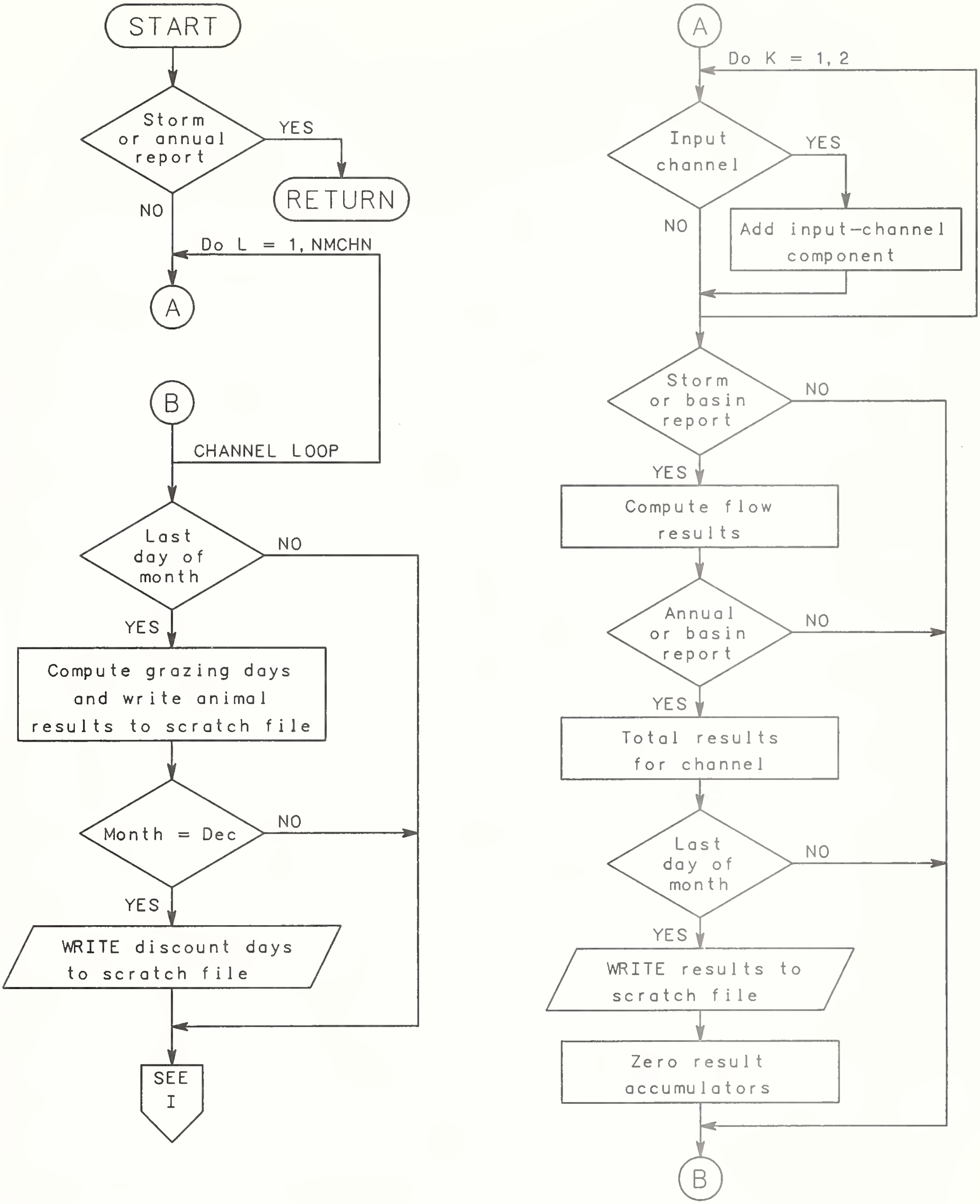


Figure 3.13
Subroutine DAYSUM: Generate daily report.

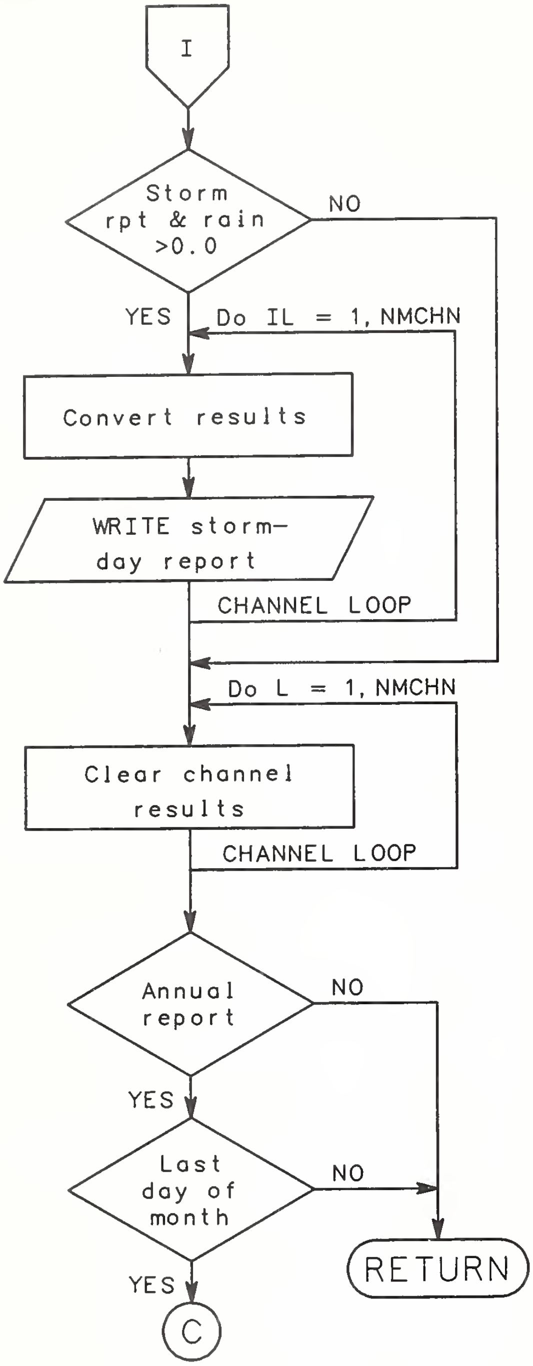
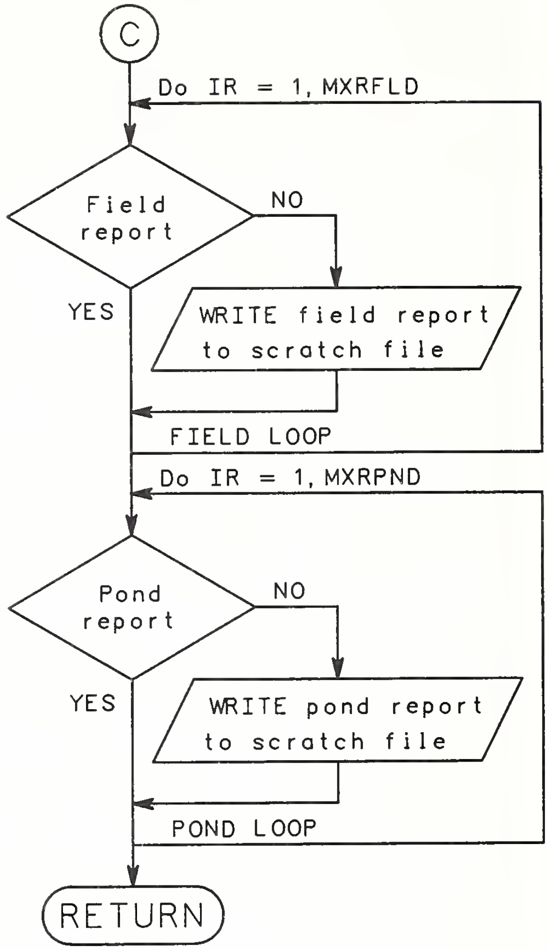


Figure 3.13--Continued
Subroutine DAYSUM: Generate daily report.



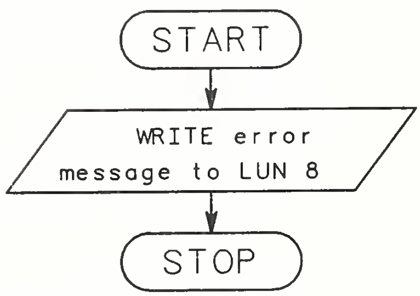


Figure 3.14
Subroutine ERR:
Generate error message.

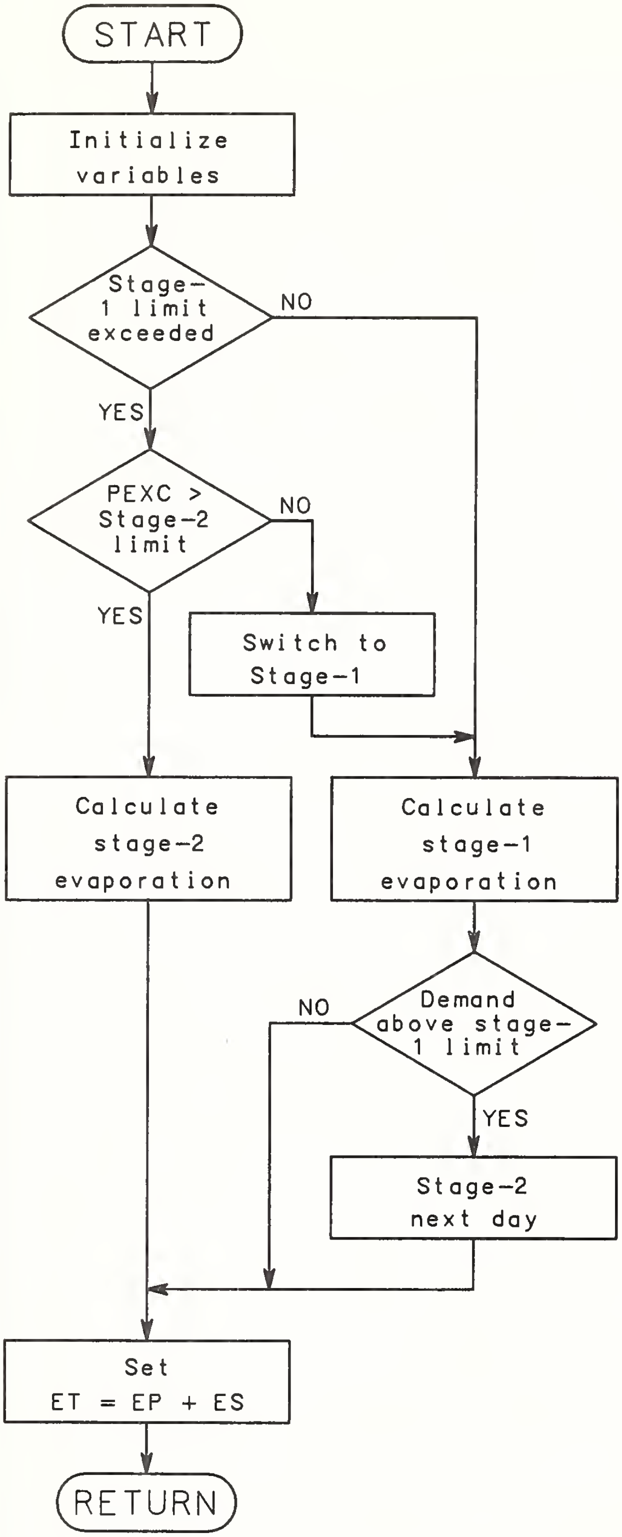


Figure 3.15
Subroutine EVAPR: Compute plant and soil evaporation.

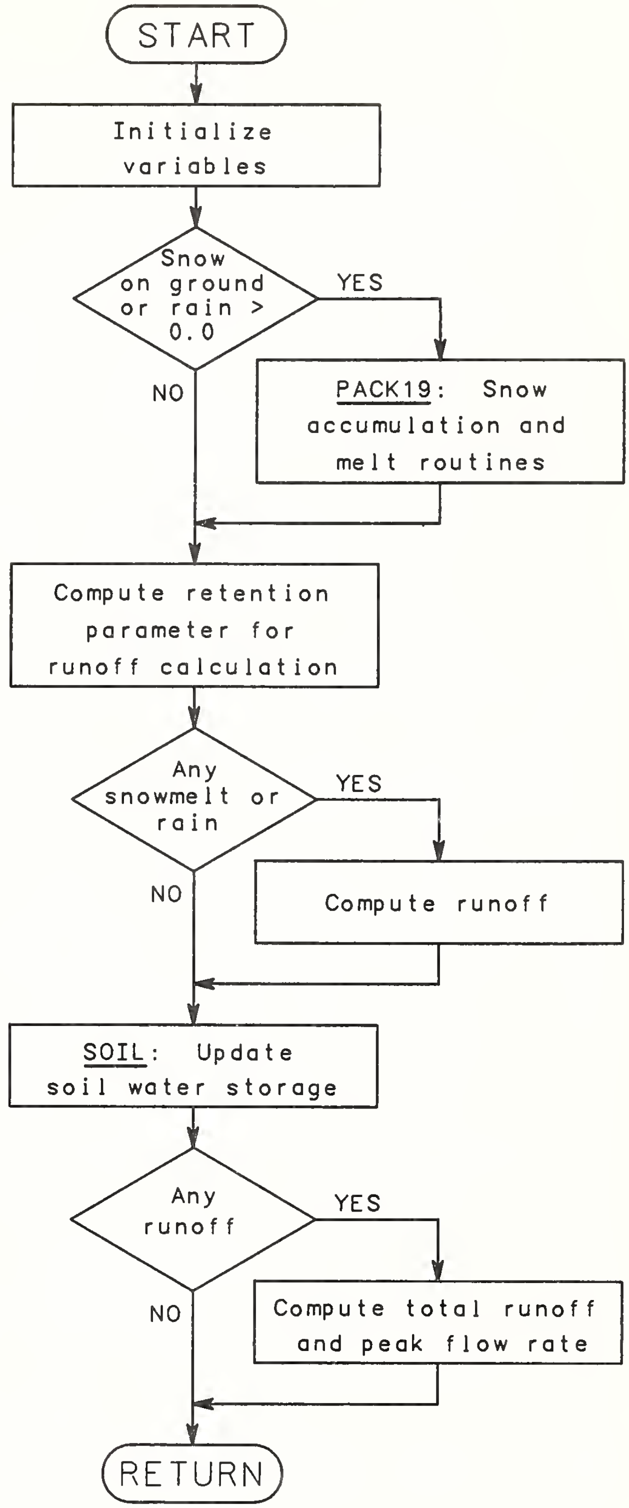


Figure 3.16
Subroutine FLDHYD: Compute surface runoff and peak runoff rate.

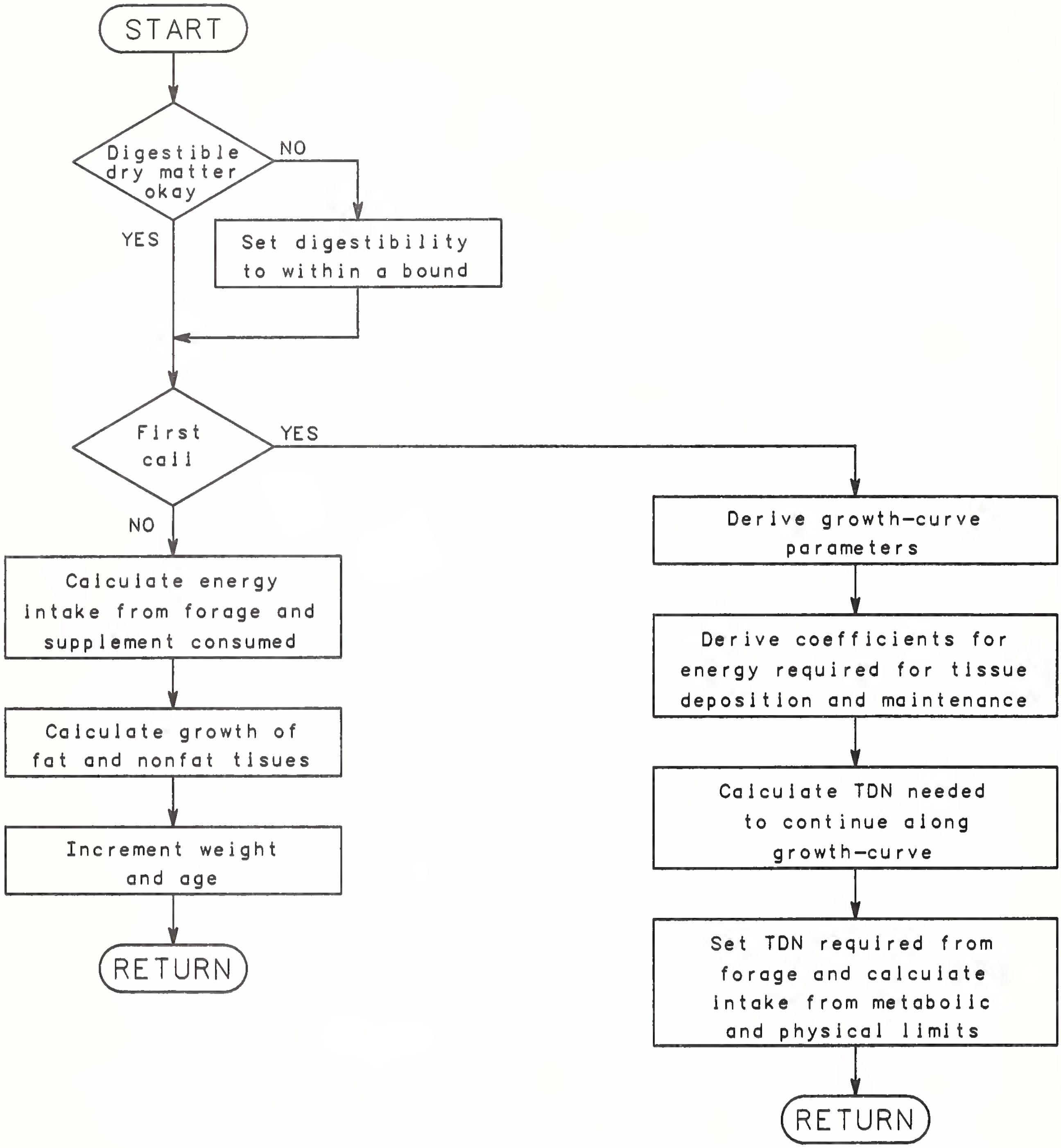


Figure 3.17
Subroutine GROW: Growth of a steer.

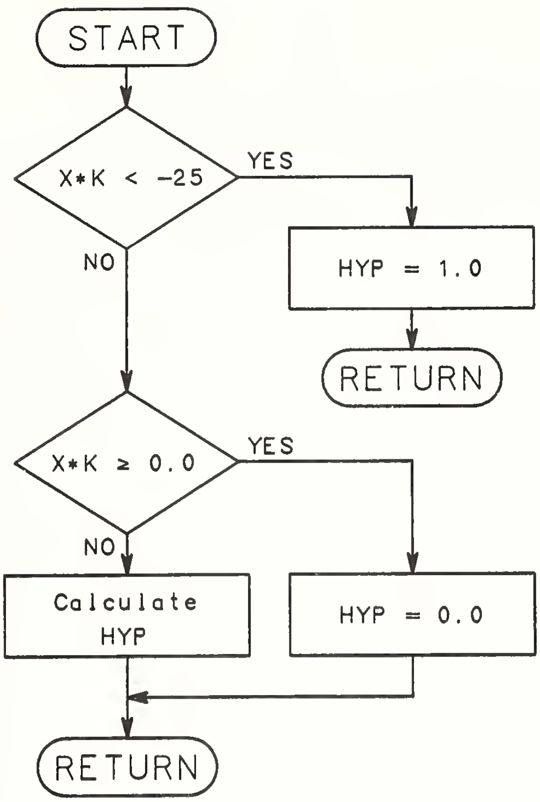


Figure 3.18
Function HYP:
Hyperbolic function.

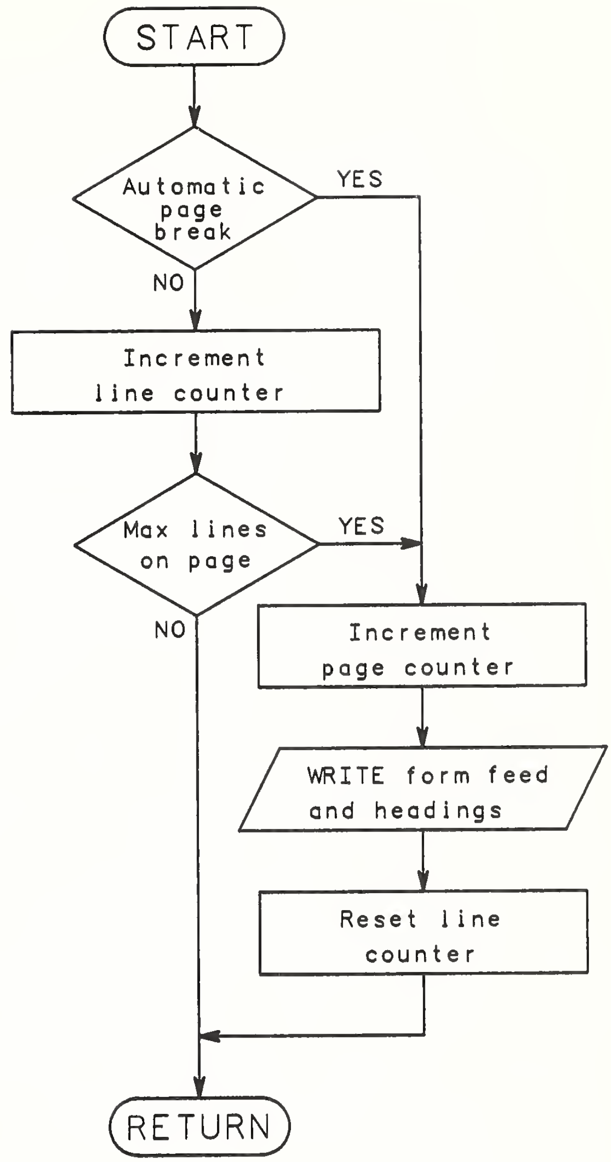


Figure 3.20
Subroutine LINE:
Generate form feeds in output file.

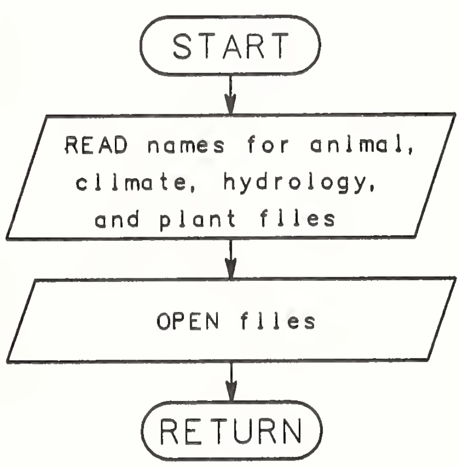


Figure 3.19
Subroutine IOSET:
Link input files.

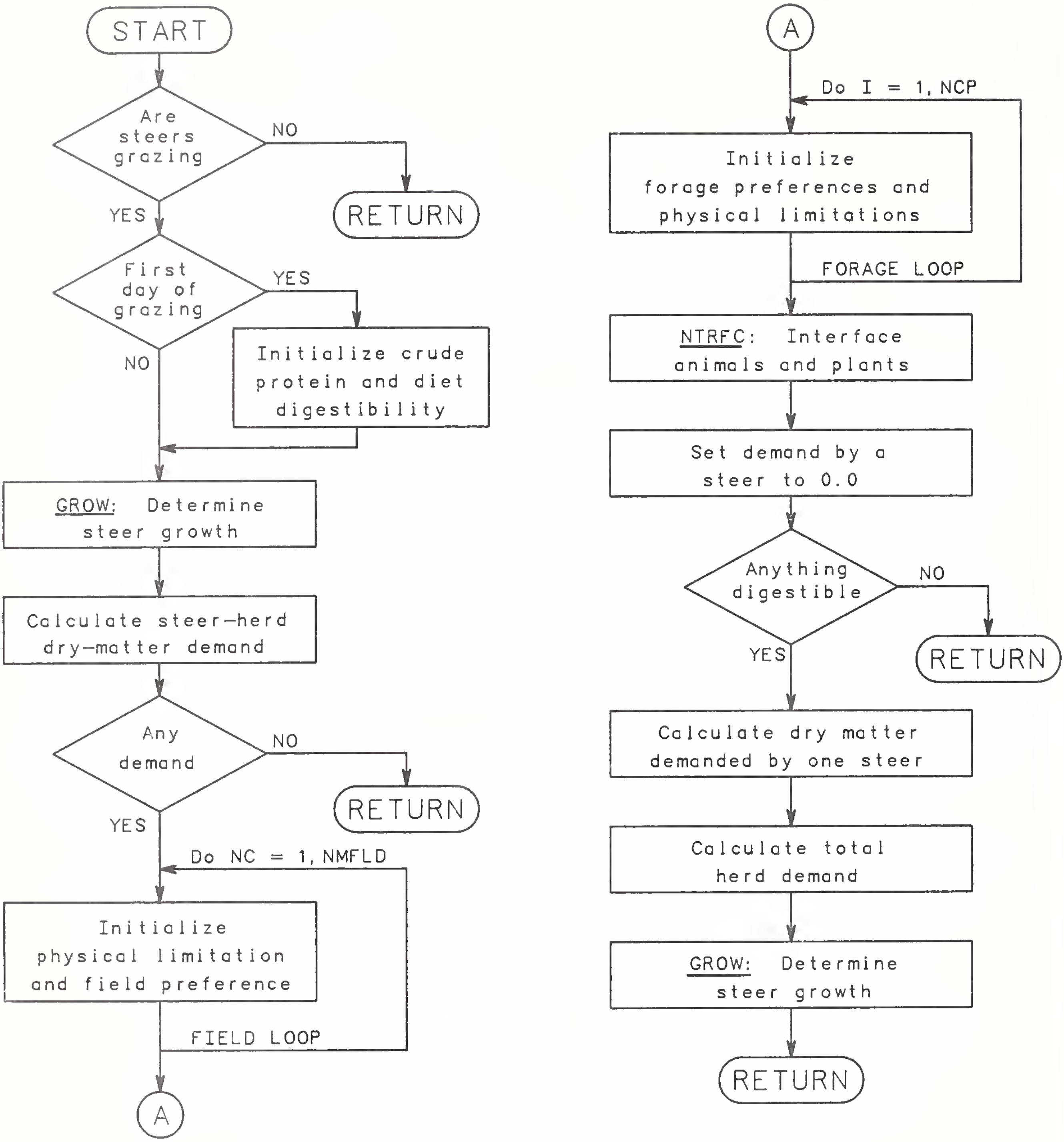


Figure 3.21
Subroutine LVSTK: Allow for livestock usage.

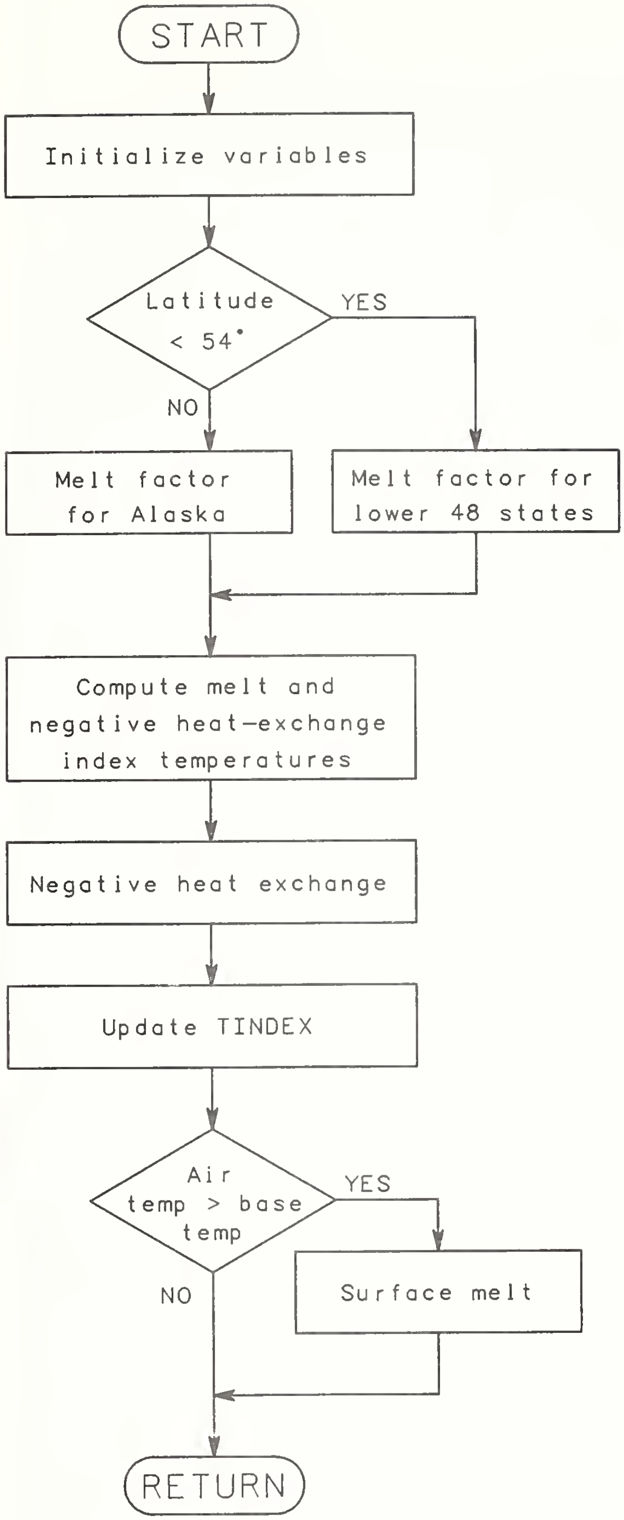


Figure 3.22
Subroutine MELT19: Compute surface melt.

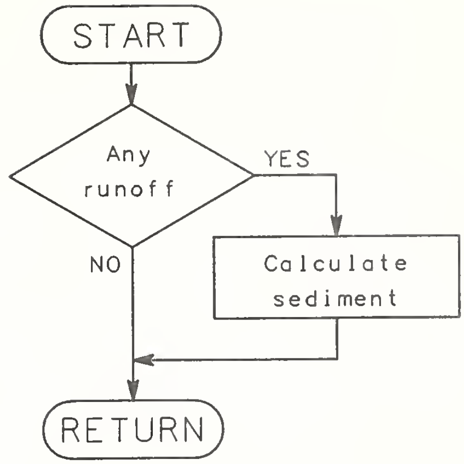


Figure 3.23
Subroutine MUSLE: Compute sediment yield from a field.

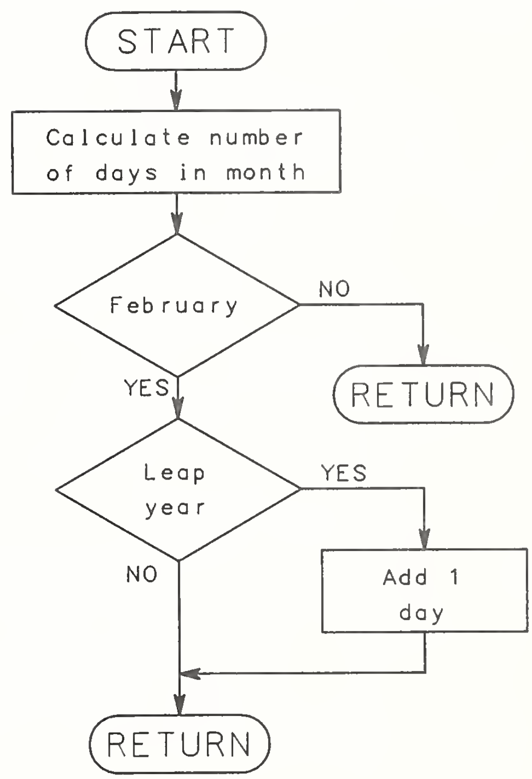


Figure 3.24
Subroutine NDPM: Calculate number of days in the month.

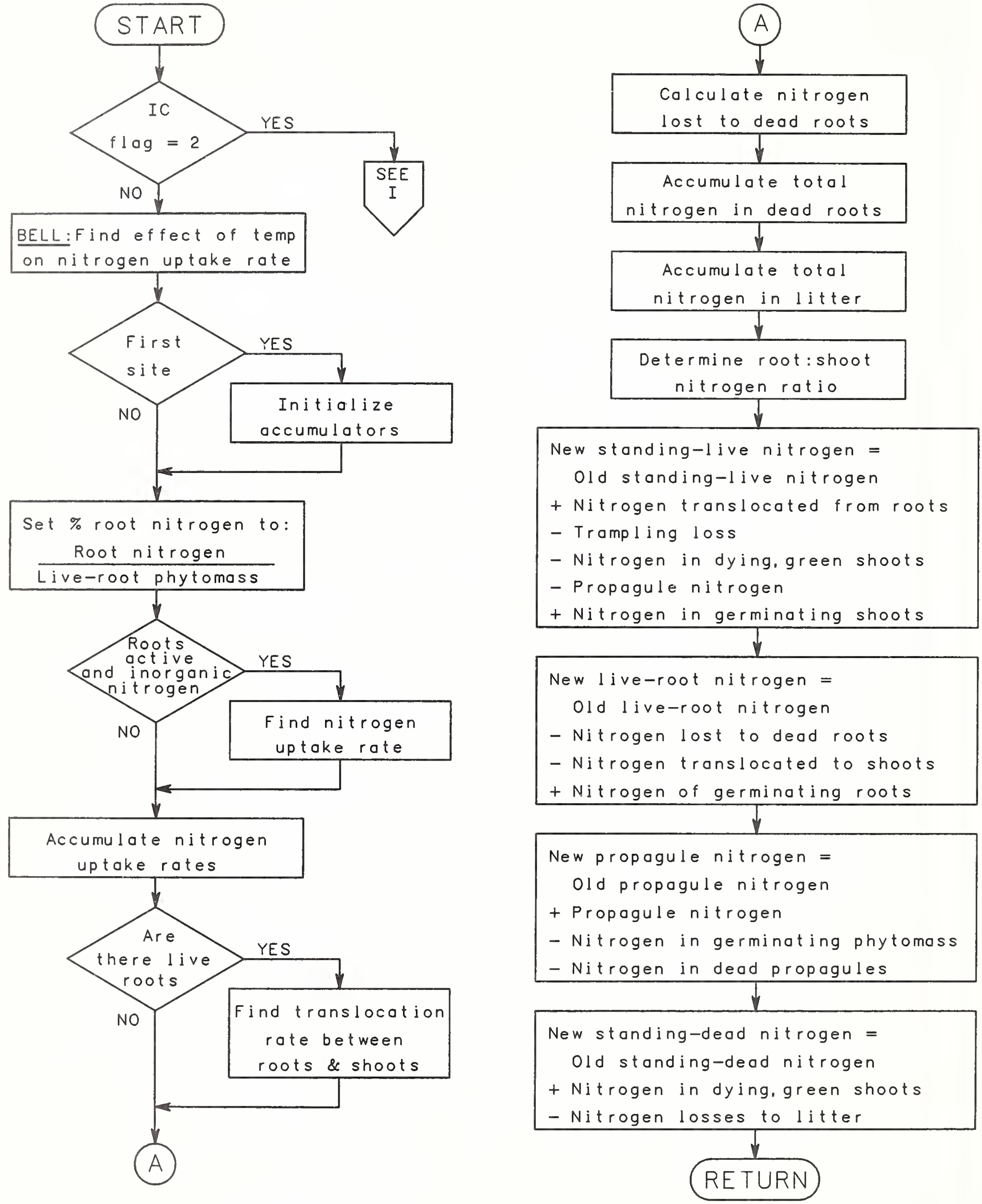


Figure 3.25
Subroutine NITE: Plant species nitrogen model.

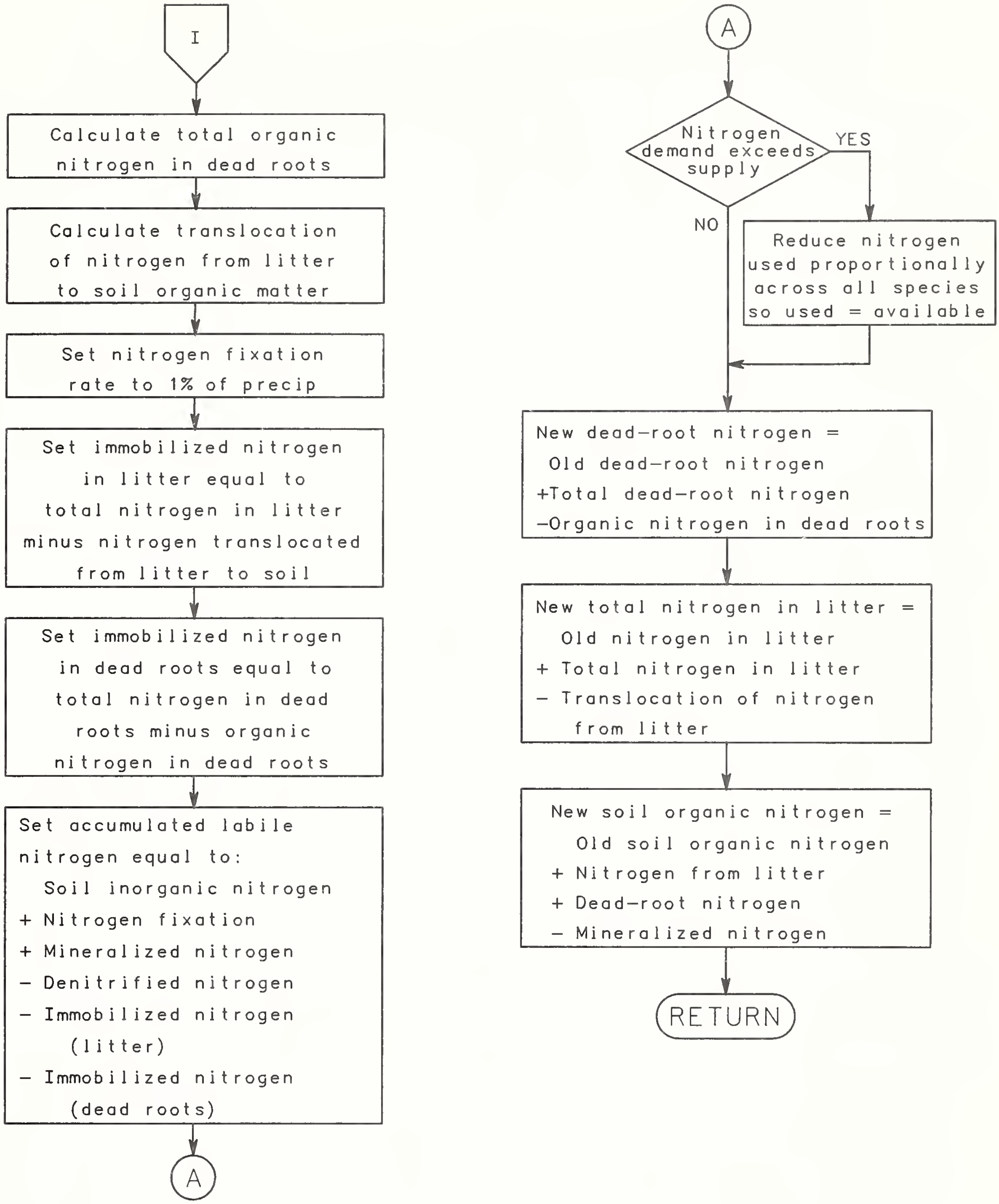


Figure 3.25--Continued
Subroutine NITE: Plant species nitrogen model.

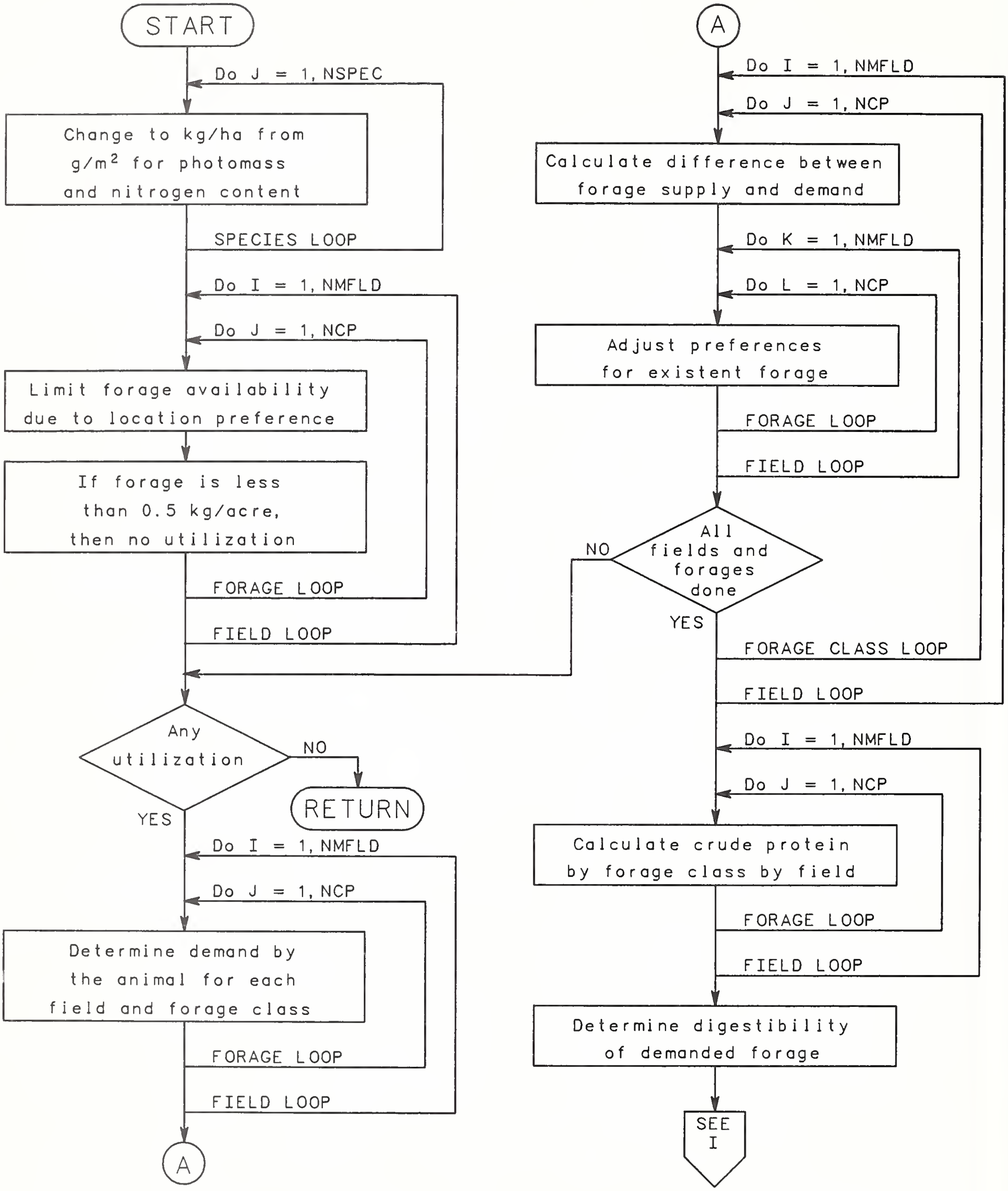


Figure 3.26
Subroutine NTRFC: Interface of animal and plant components.

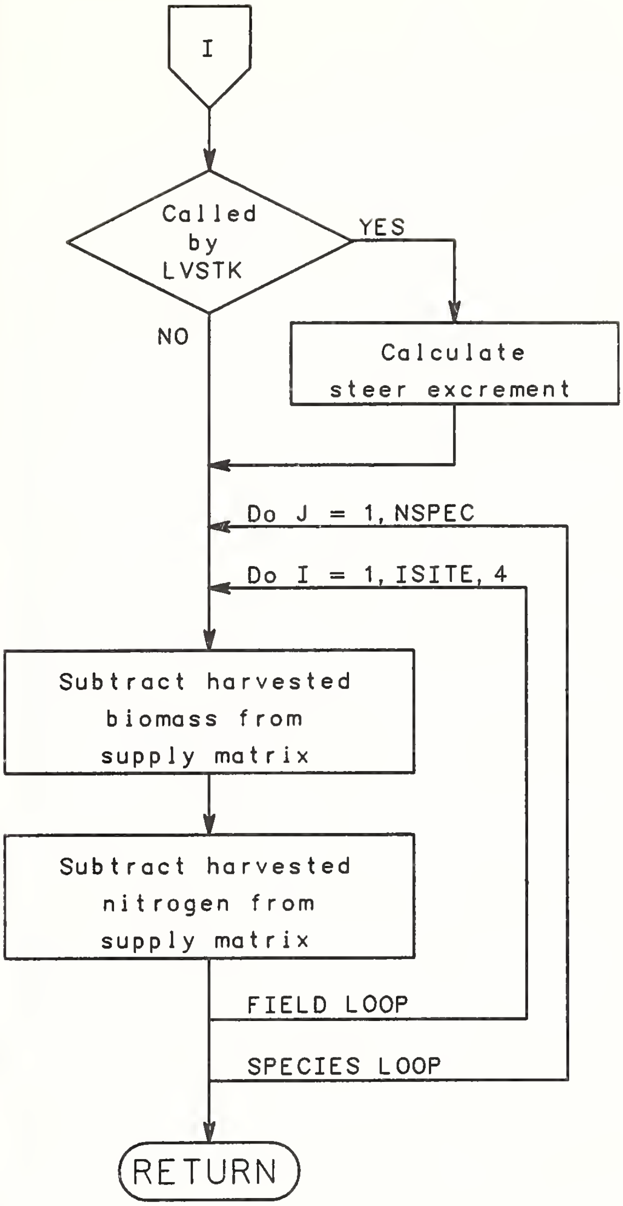


Figure 3.26--Continued
Subroutine NTRFC: Interface of animal and plant components.

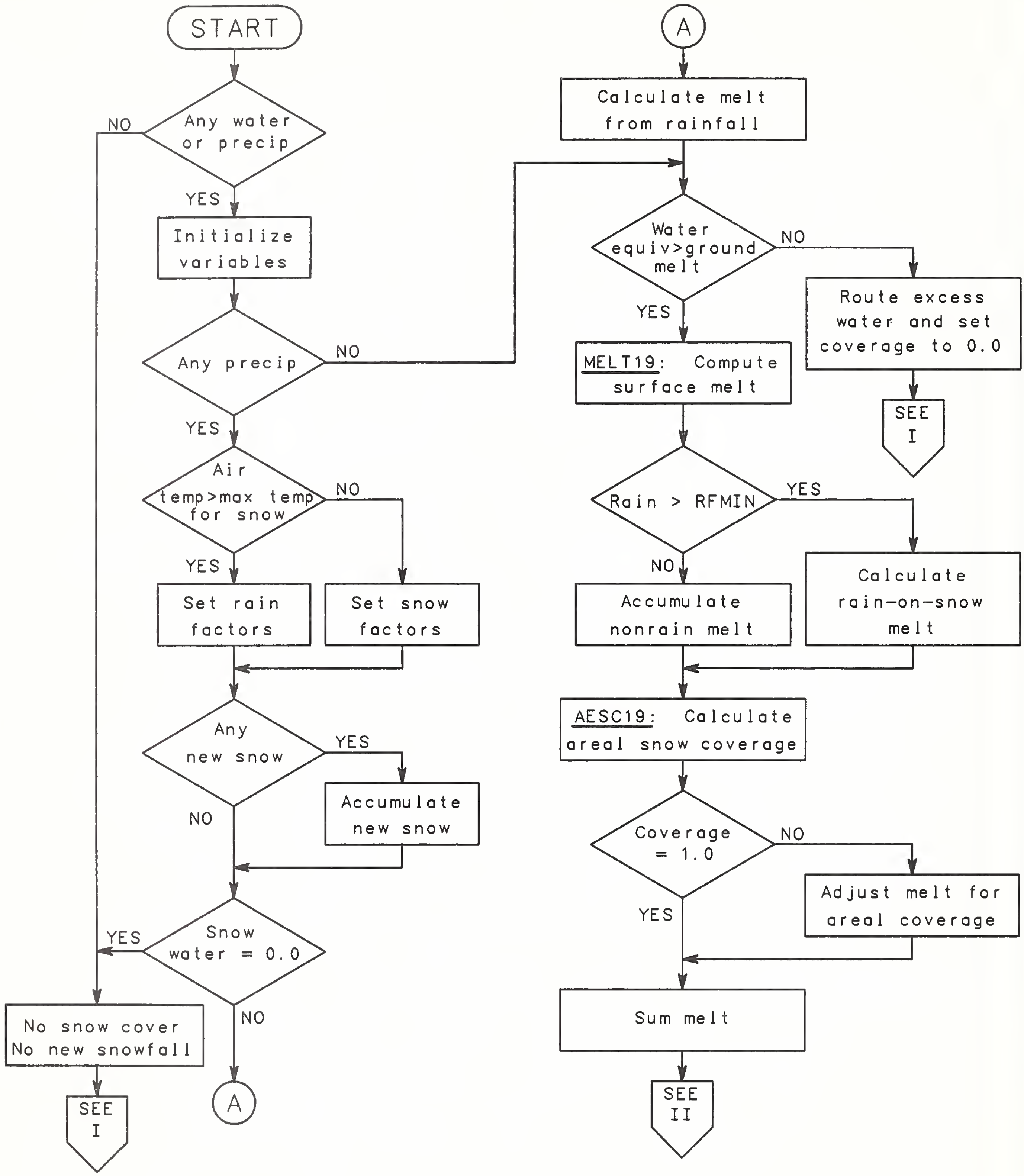


Figure 3.27
Subroutine PACK19: Snow accumulation and melt routine.

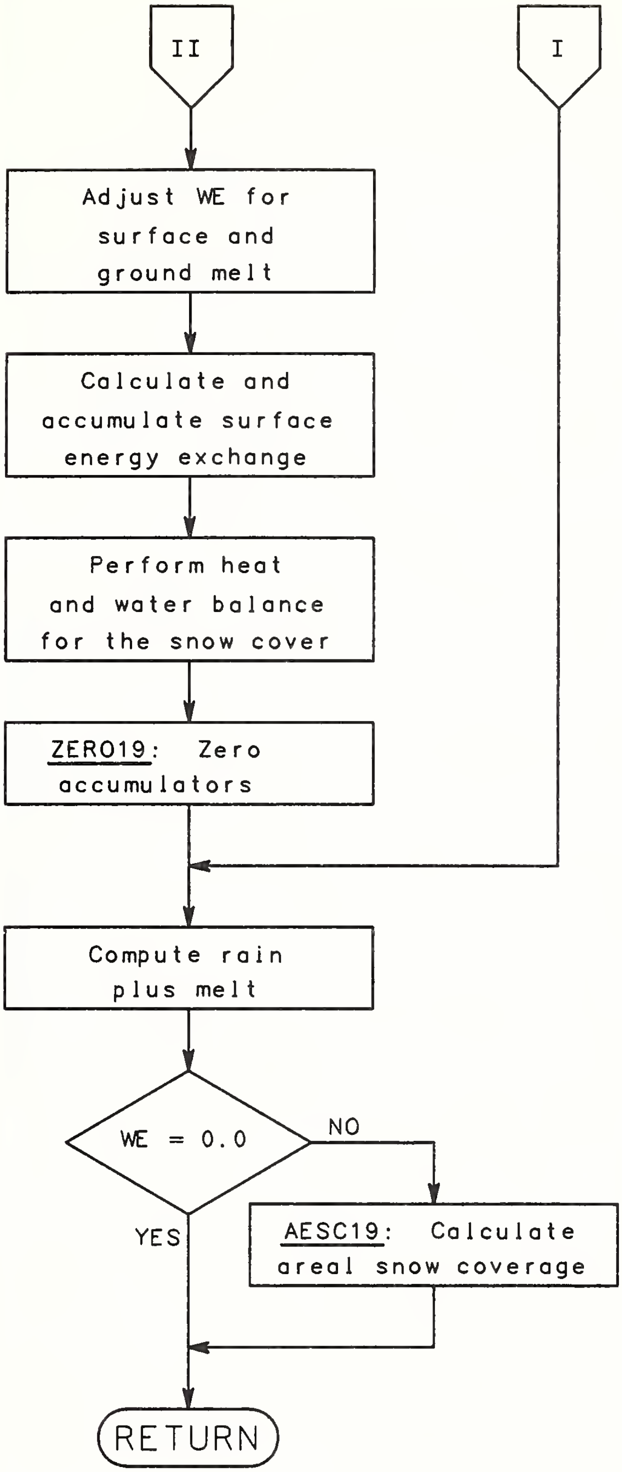


Figure 3.27--Continued
Subroutine PACK19: Snow accumulation and melt routine.

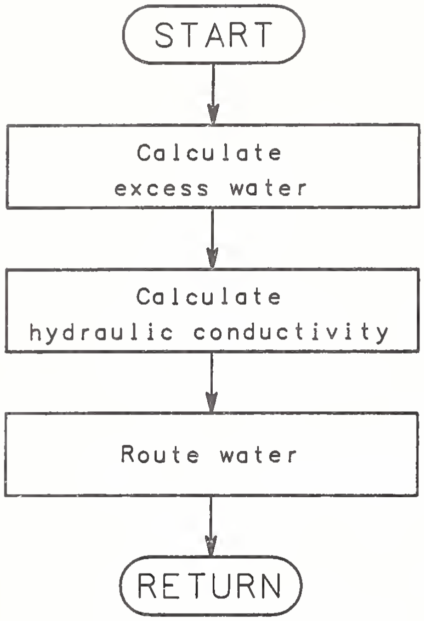


Figure 3.28
Subroutine PERC: Percolate water through soil layers.

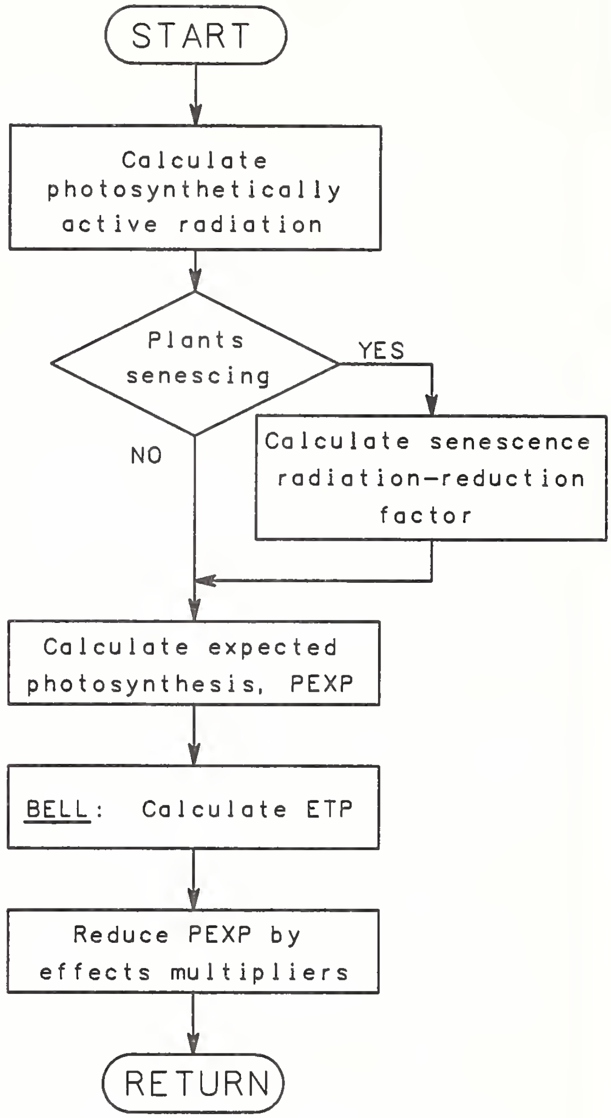


Figure 3.29
Function PEXP: Calculate expected photosynthesis.

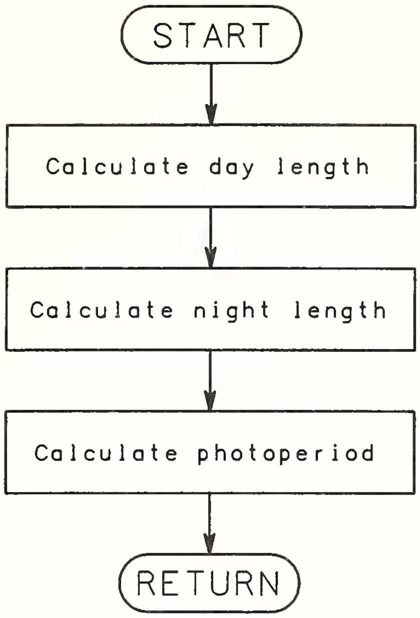


Figure 3.30
Function PHOPER: Calculate photoperiod.

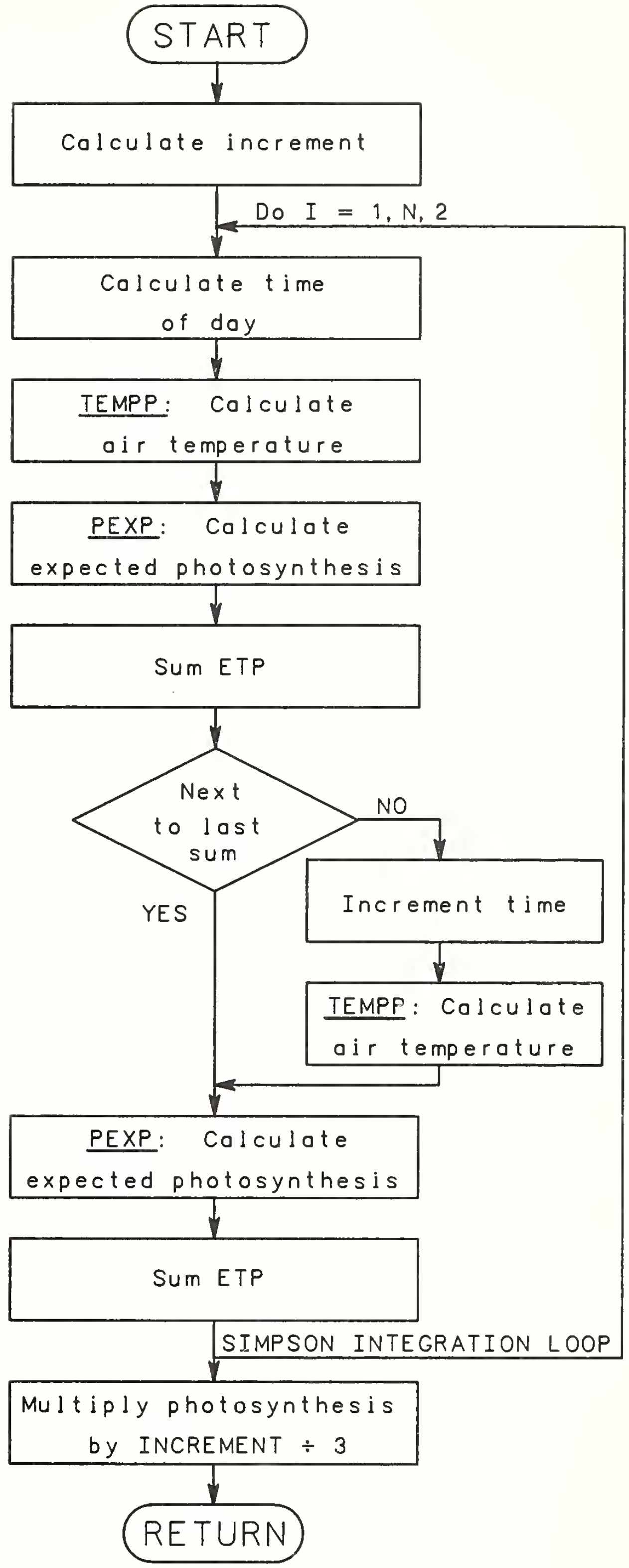


Figure 3.31
Subroutine PHOTO: Numerically integrate daily photosynthesis.

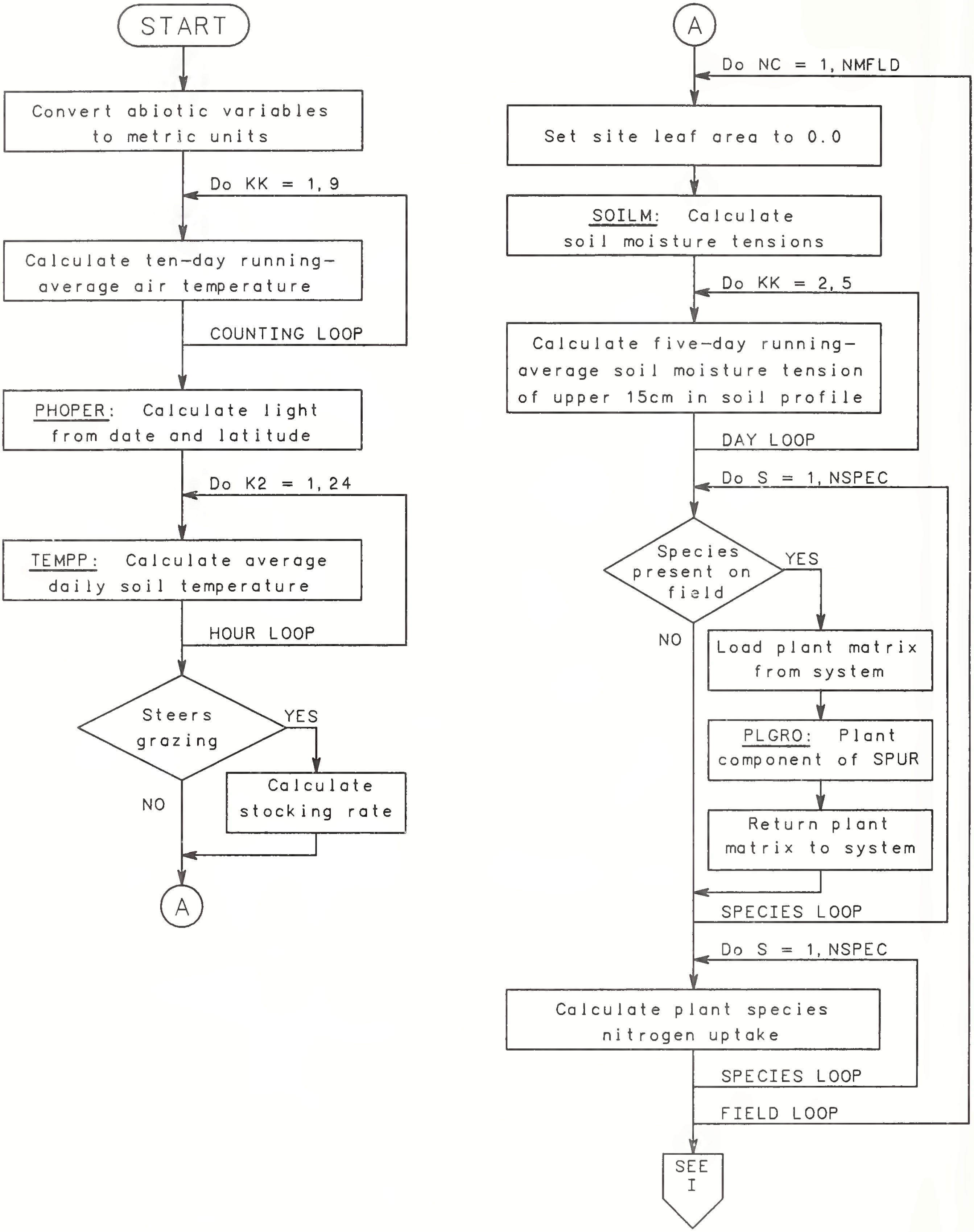


Figure 3.32
Subroutine PLANT: Plant component.

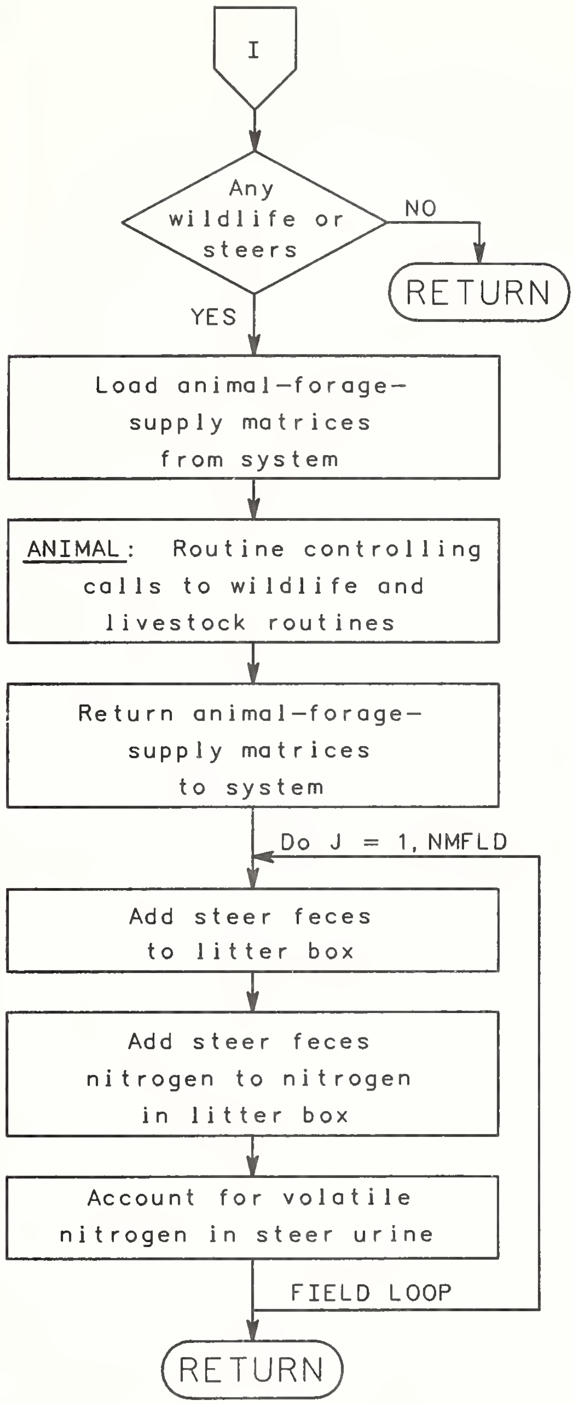


Figure 3.32--Continued
Subroutine PLANT: Plant component.

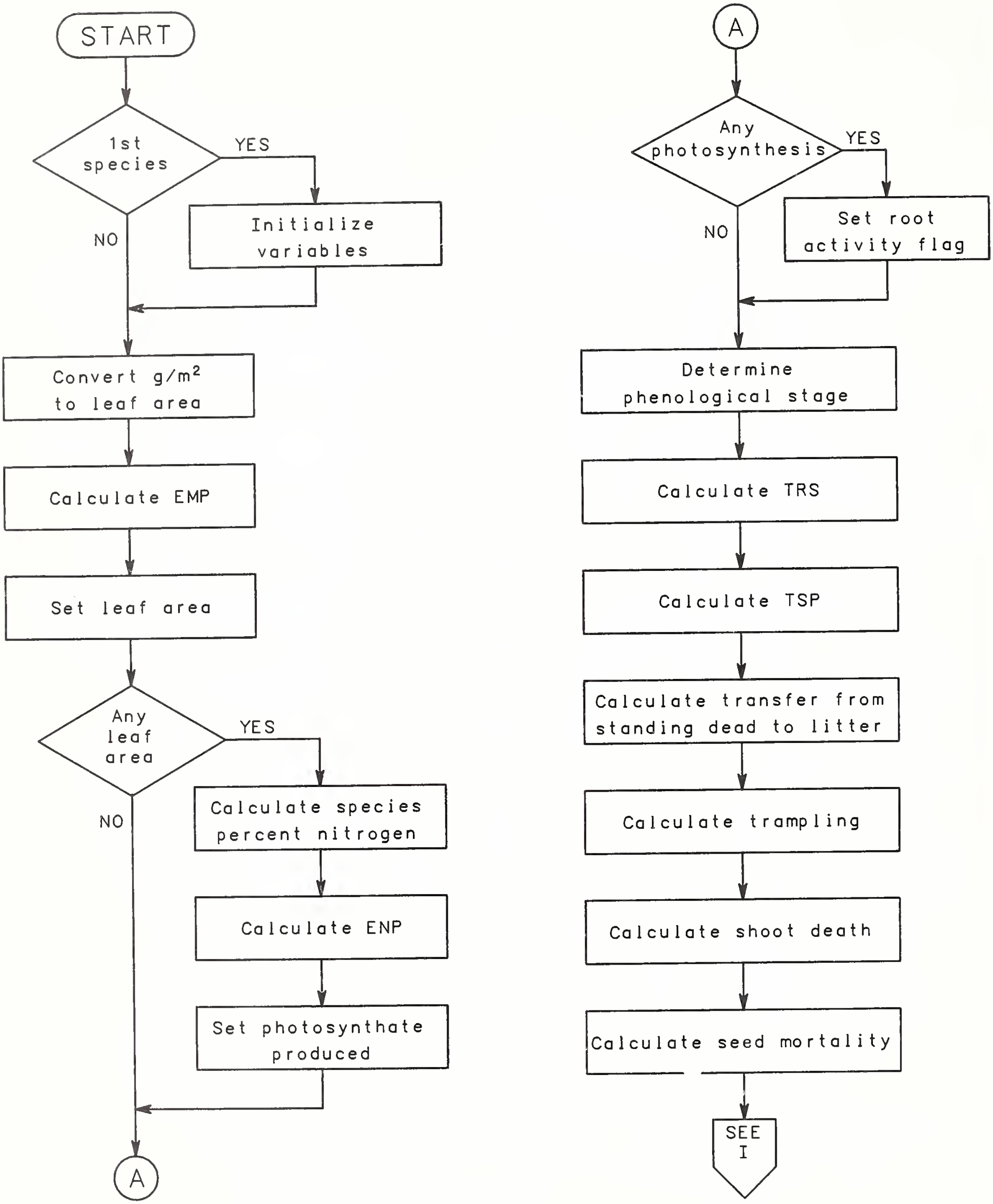


Figure 3.33
Subroutine PLGRO: Growth of plants.

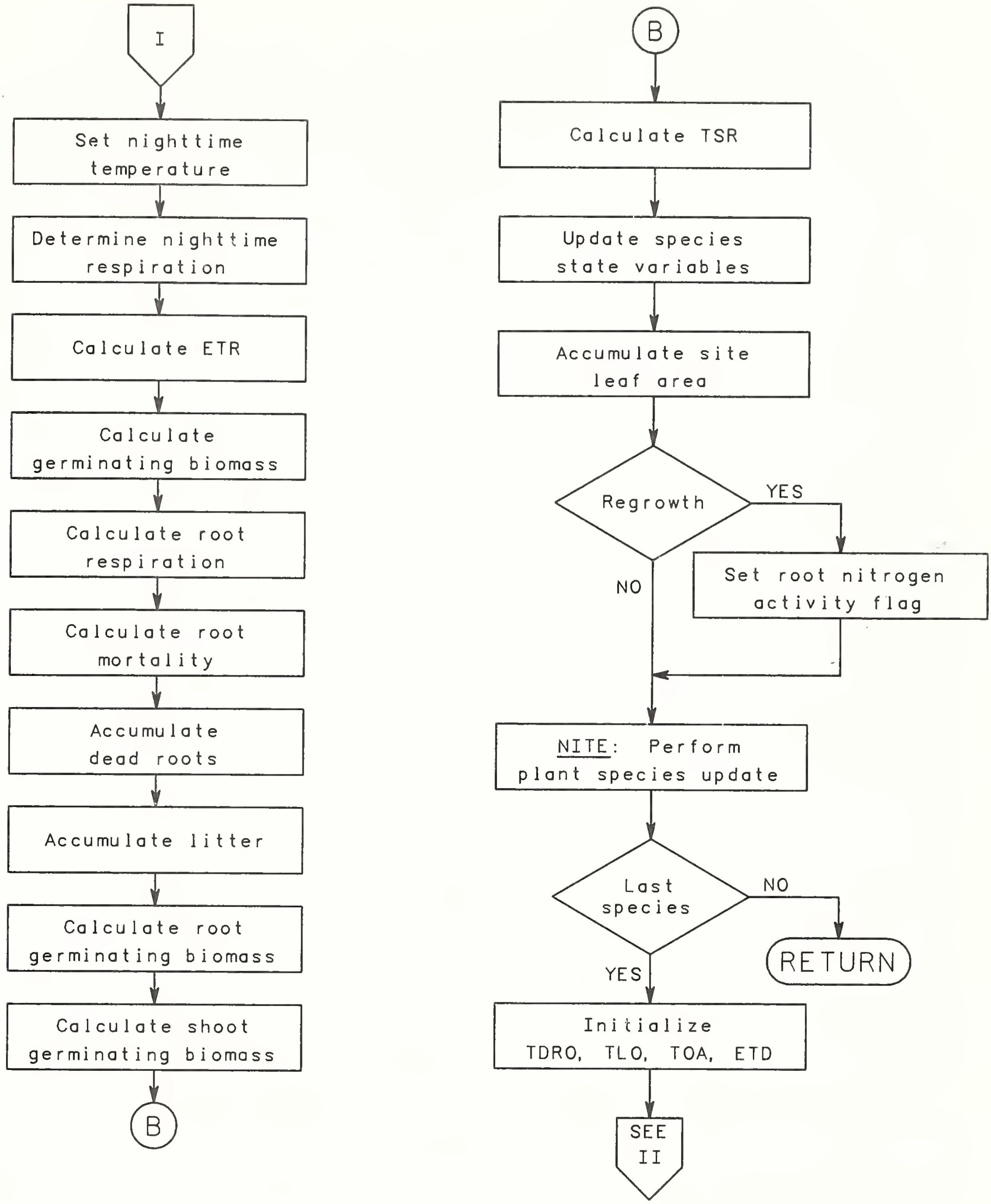


Figure 3.33--Continued
Subroutine PLGRO: Growth of plants.

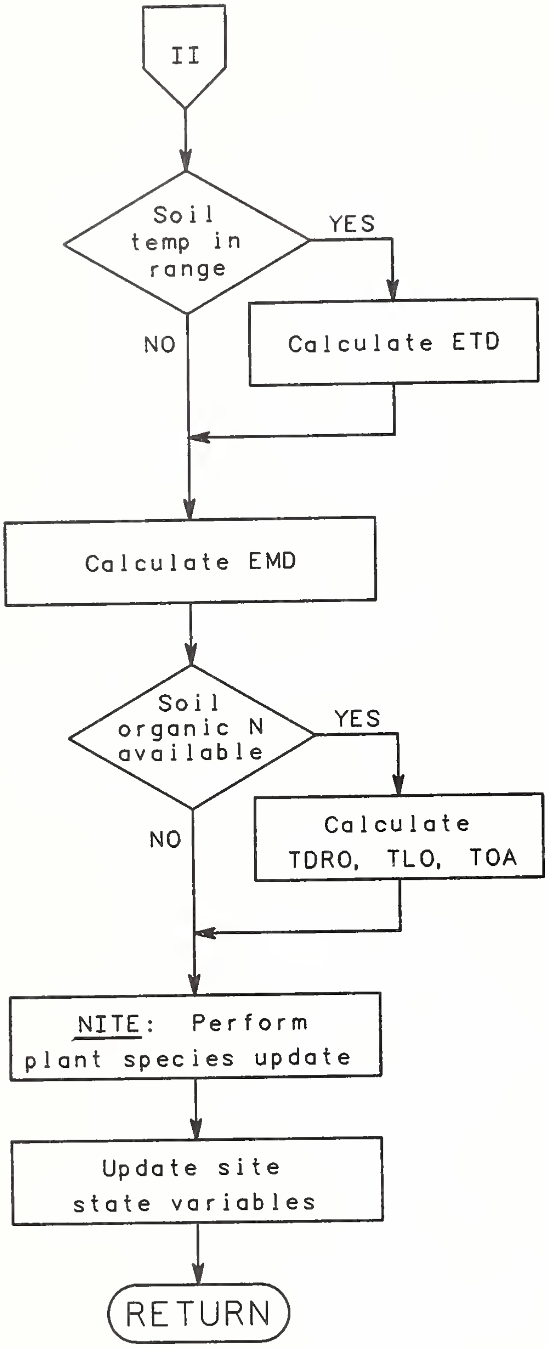


Figure 3.33--Cantinued
Subroutine PLGRO: Grawth
af plants.

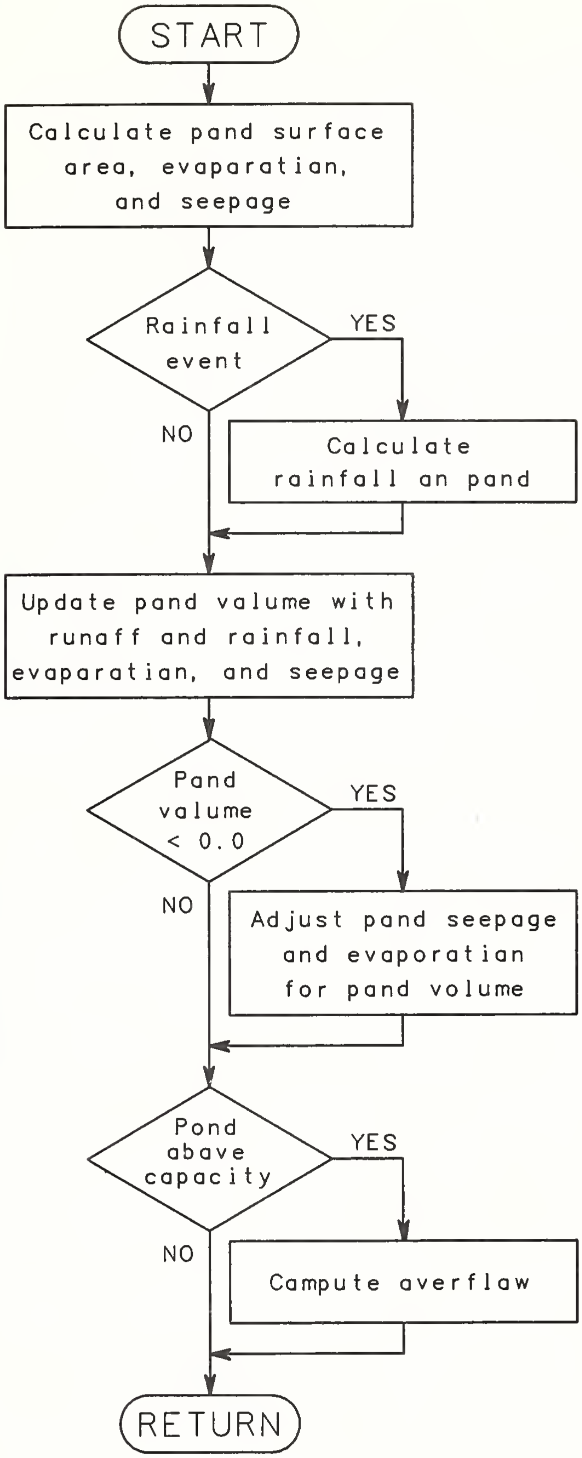


Figure 3.34
Subroutine PONDF: Correct runoff due to pond.

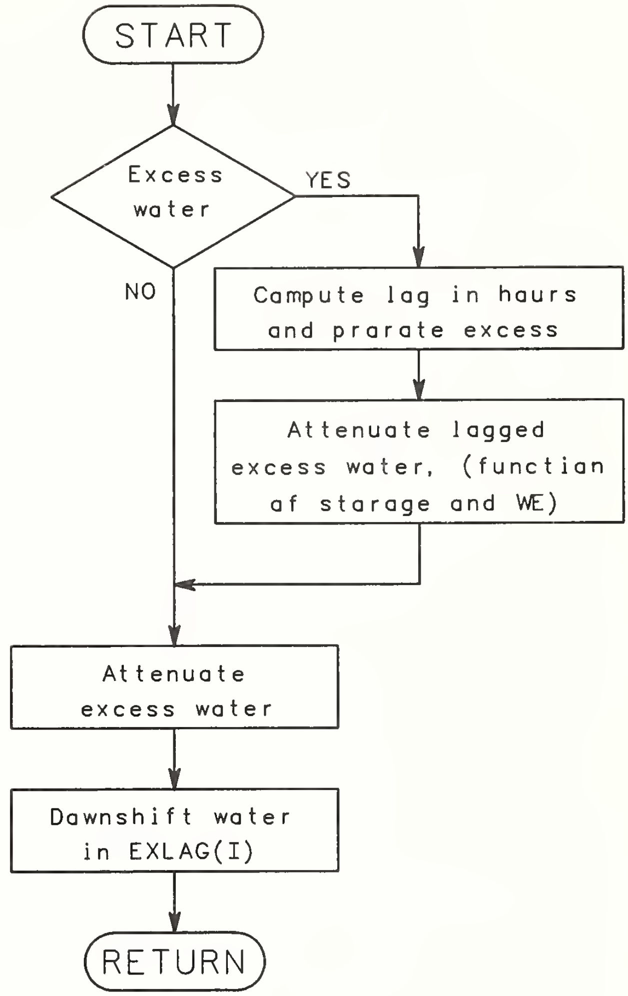


Figure 3.35
Subroutine ROUT19: Route excess water through snow.

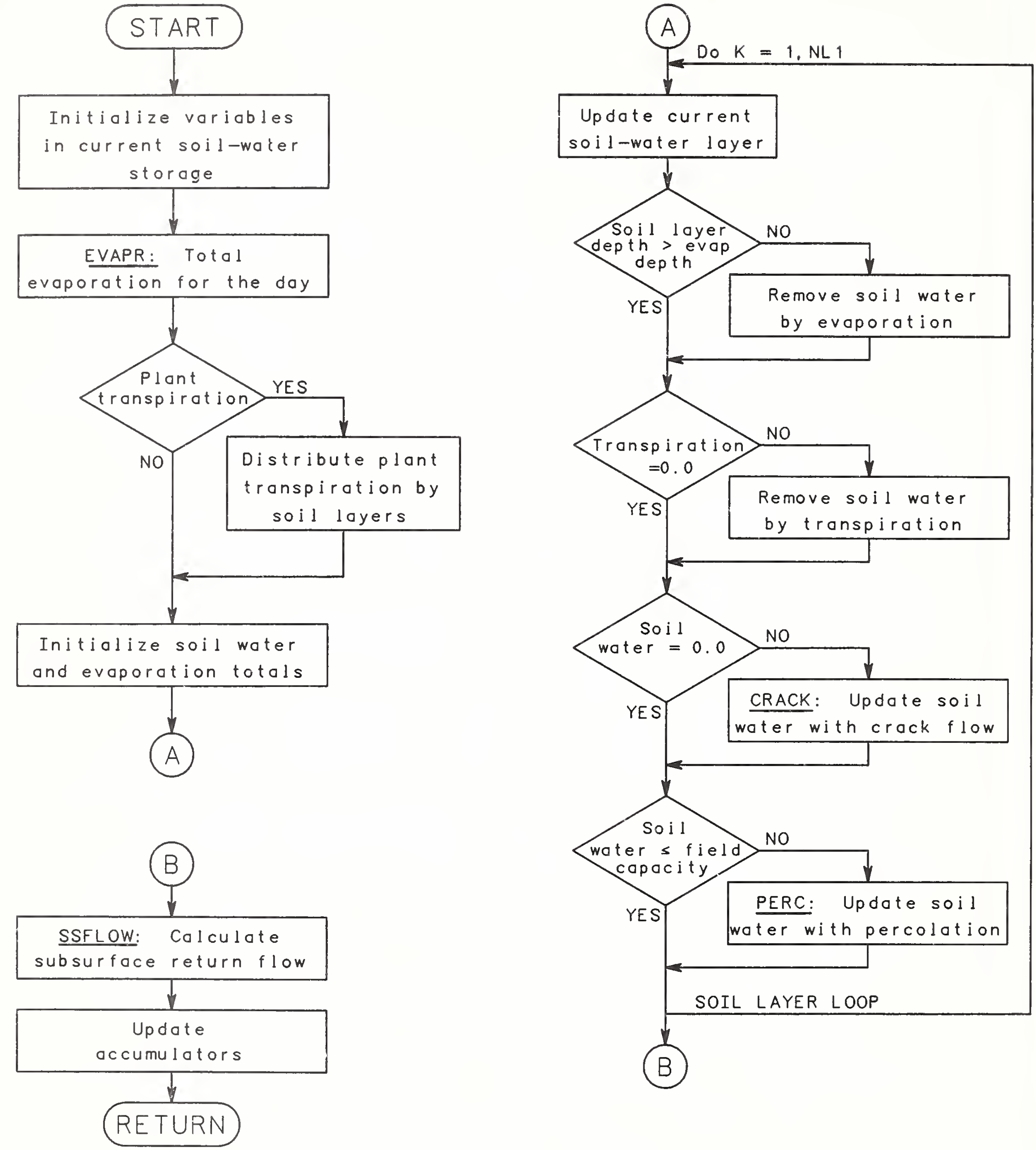


Figure 3.36
Subroutine SOIL: Update soil-water storage.

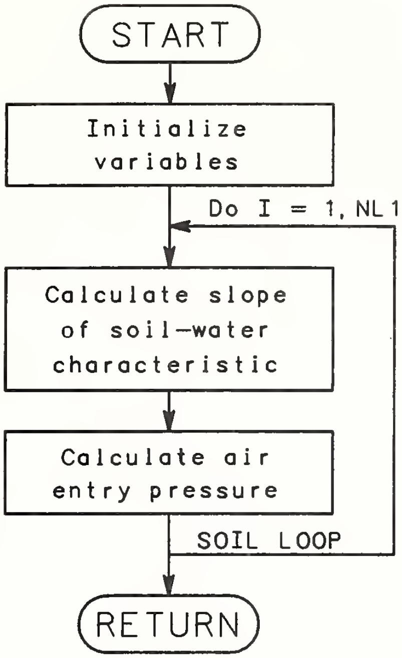


Figure 3.37
Subroutine SOILC: Determine the moisture characteristics.

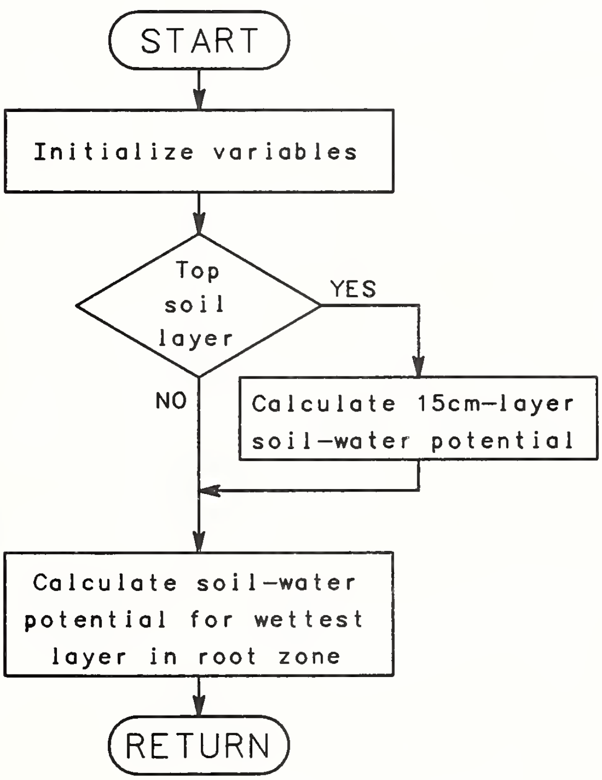


Figure 3.38
Subroutine SOILM: Calculate soil-water potentials.

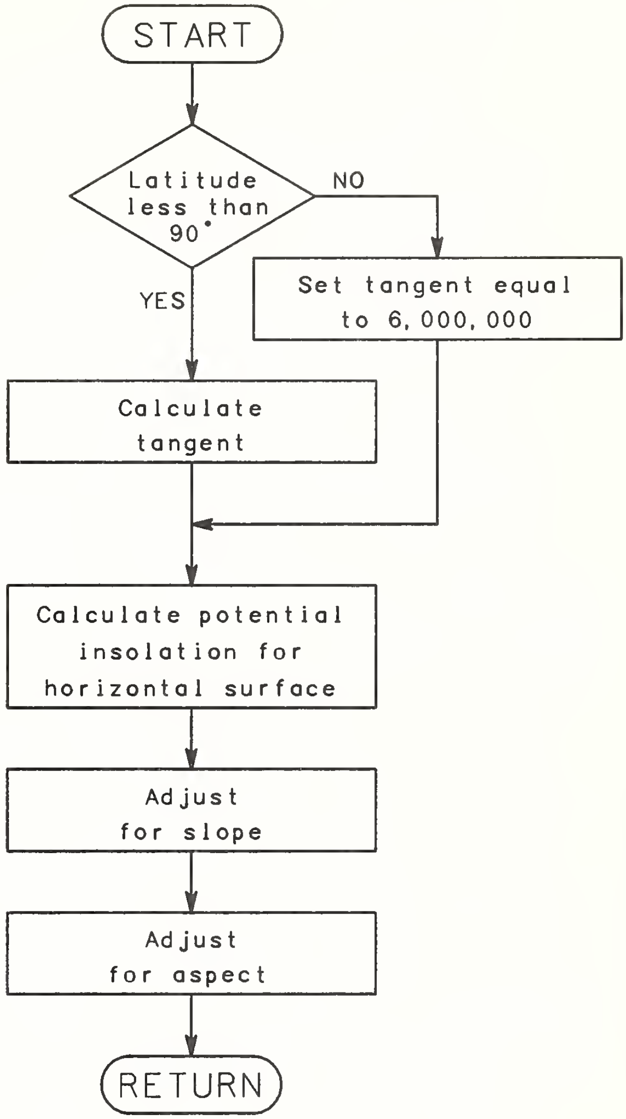


Figure 3.39
Function SOLADJ: Correct solar radiation.

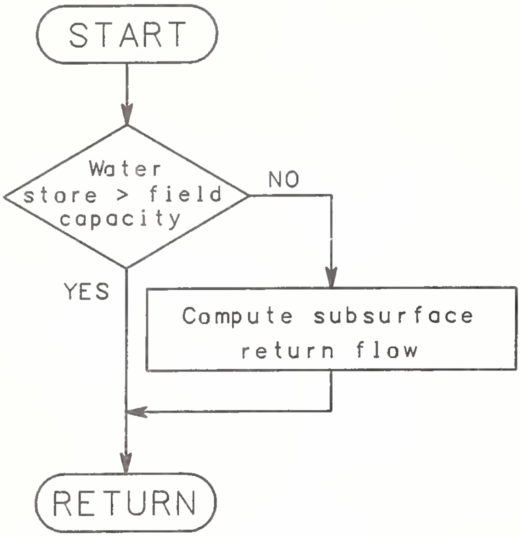


Figure 3.40
Subroutine SSFLOW:
Calculate subsurface flow.

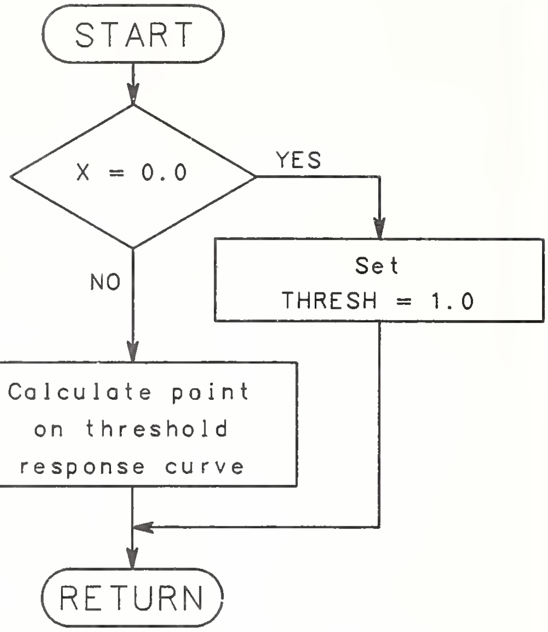


Figure 3.42
Function THRESH:
Determine plant threshold.

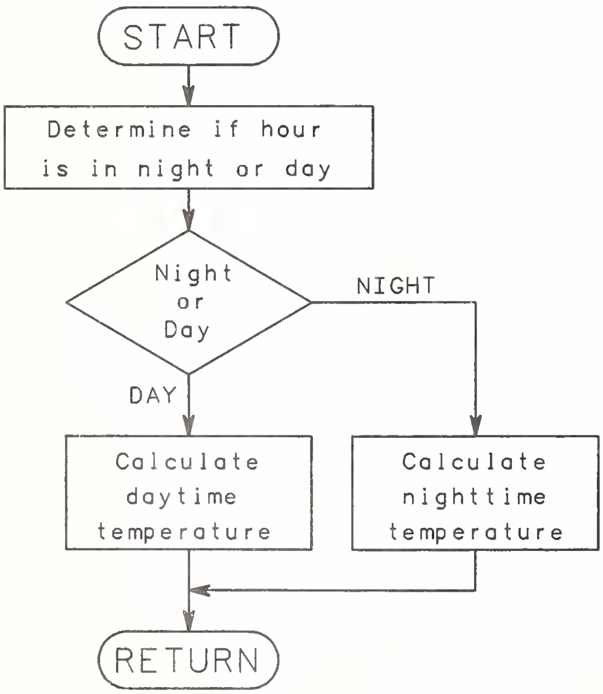


Figure 3.41
Function TEMPP:
Calculate temperature.

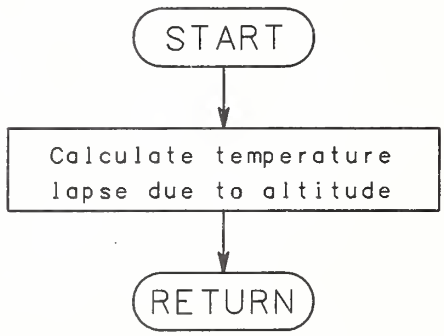


Figure 3.43
Function TLAPSE:
Calculate temperature lapse due to altitude.

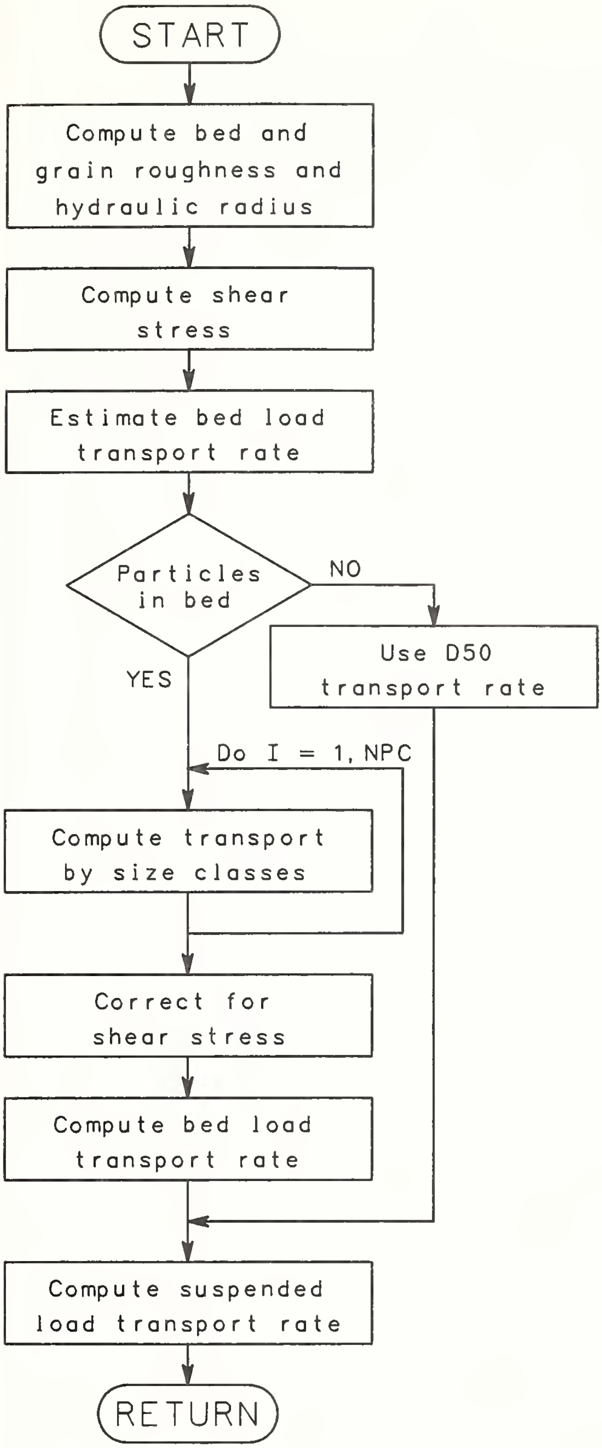


Figure 3.44
Subroutine TRATE: Calculate sediment transport rate.

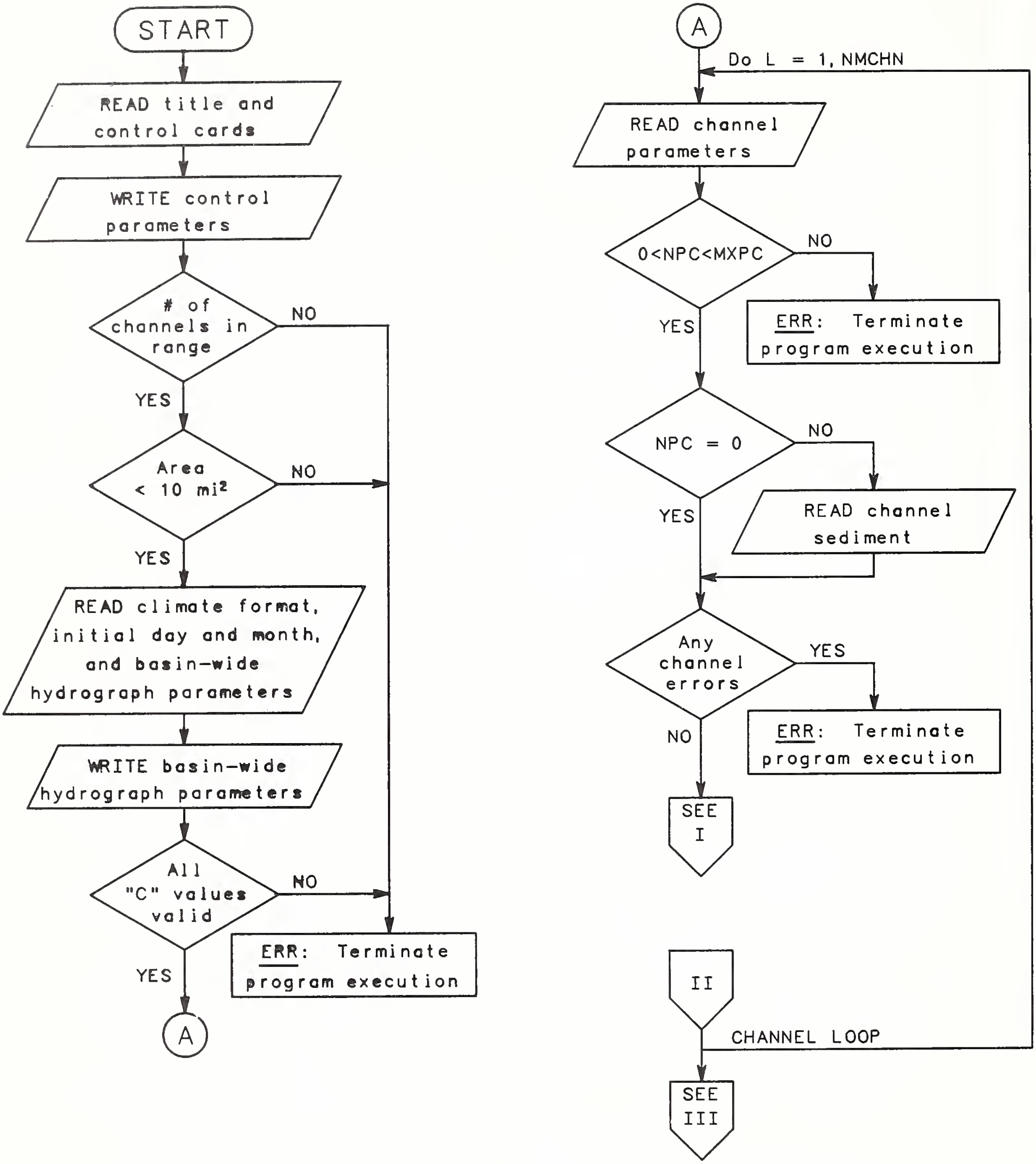


Figure 3.45
Subroutine USER: Initialization of the model.

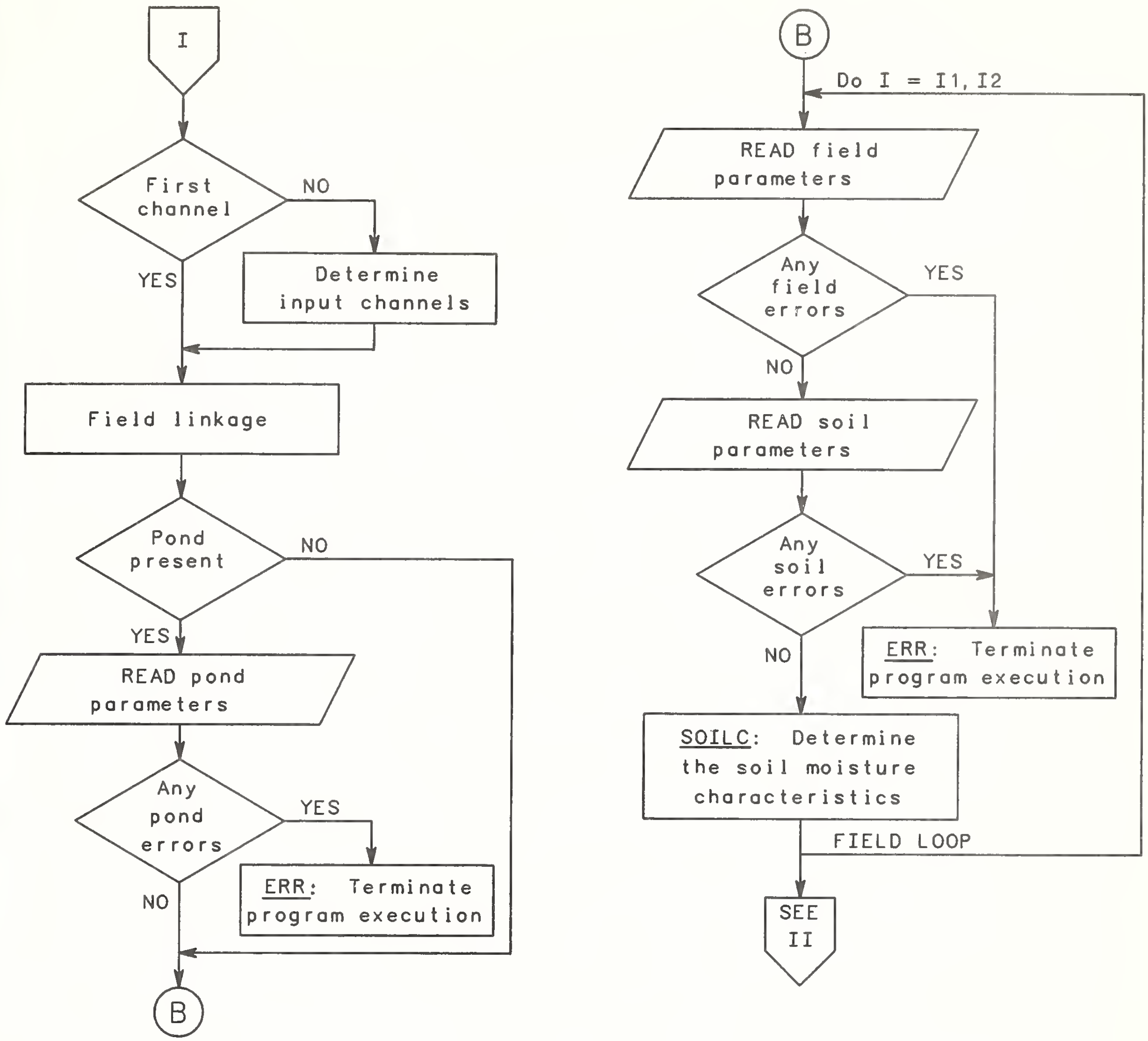


Figure 3.45--Continued
Subroutine USER: Initialization of the model.

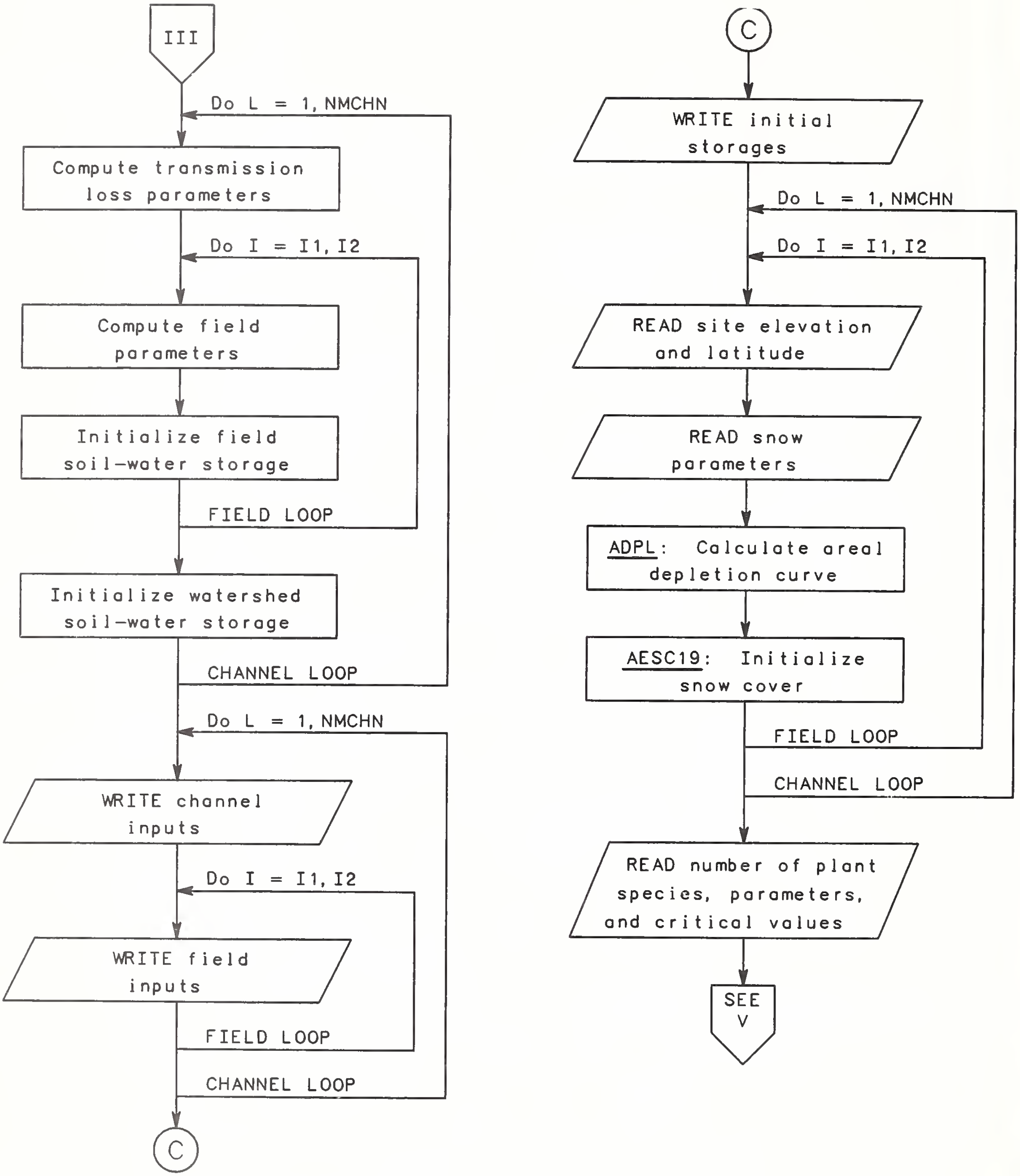


Figure 3.45--Continued
Subroutine USER: Initialization of the model.

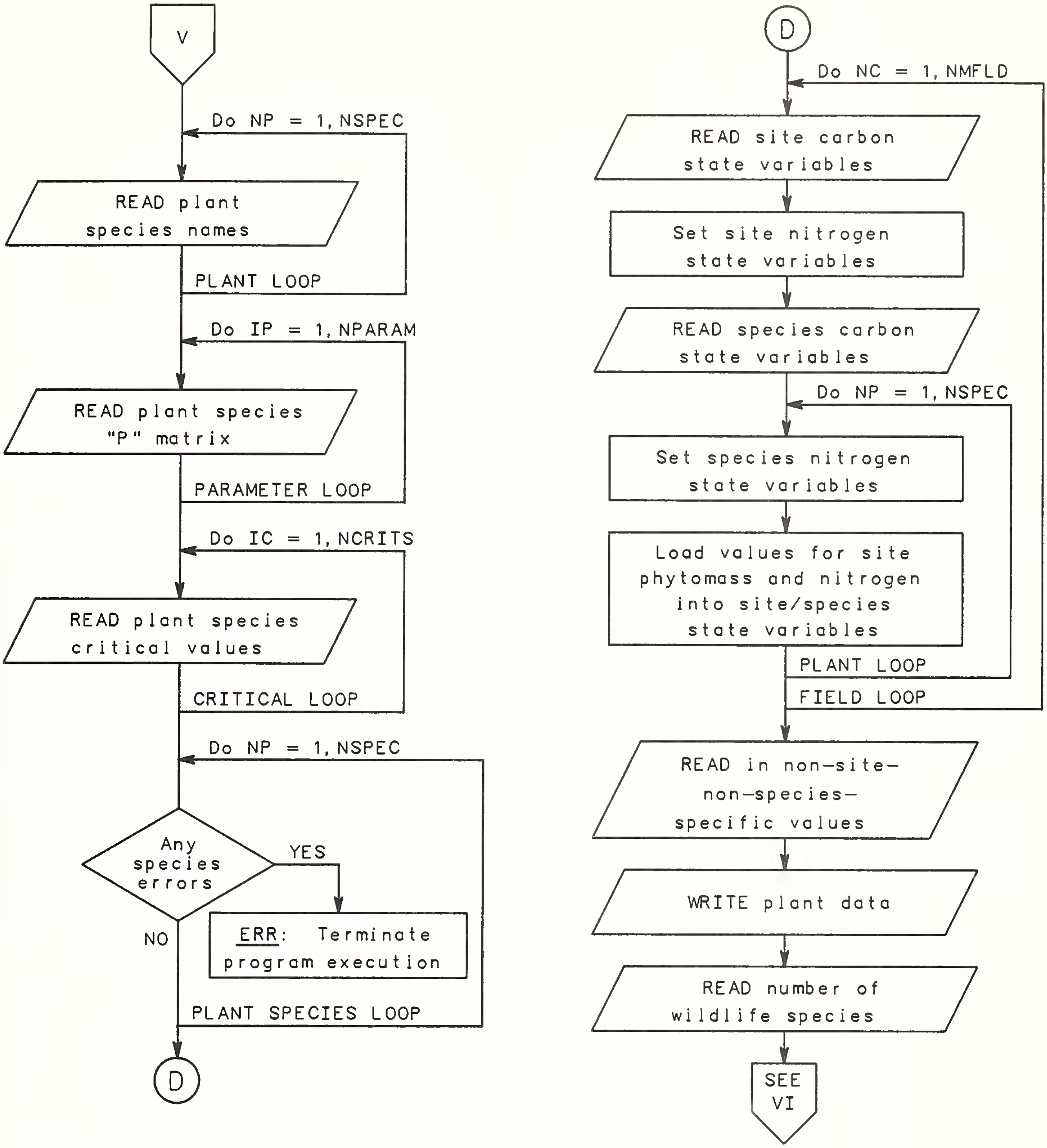


Figure 3.45--Continued
Subroutine USER: Initialization of the model.

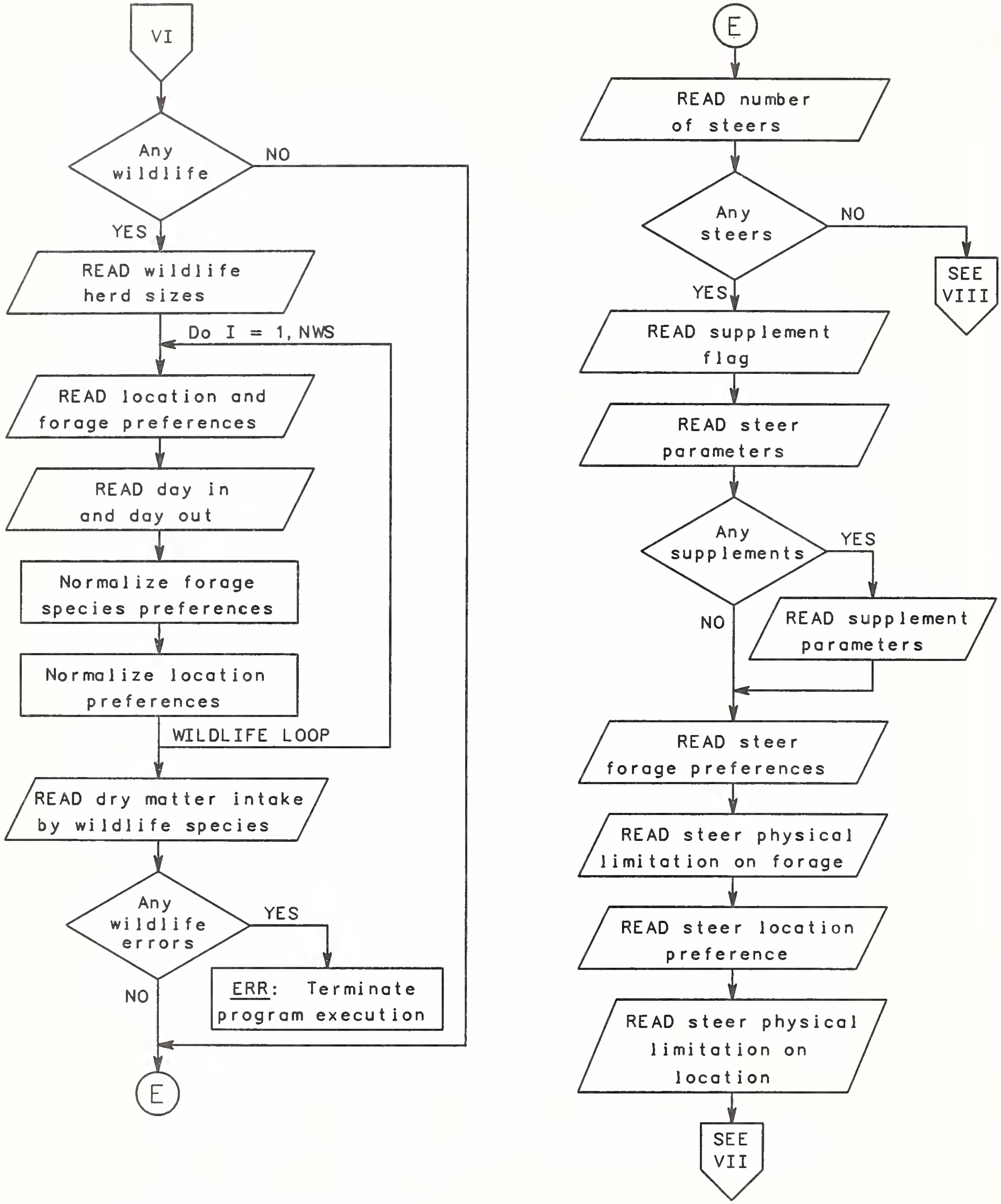


Figure 3.45--Continued
Subroutine USER: Initialization of the model.

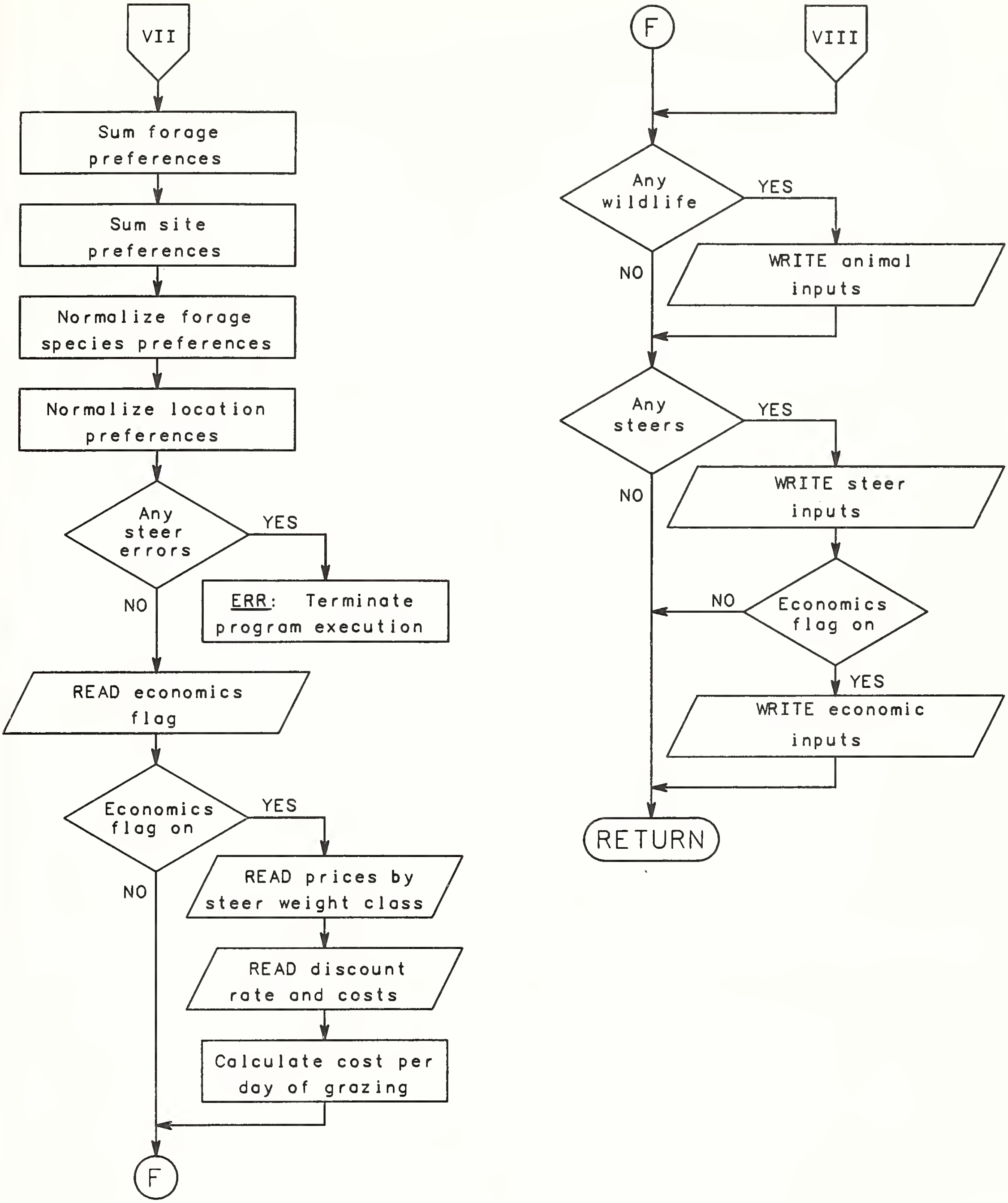


Figure 3.45--Continued
Subroutine USER: Initialization of the model.

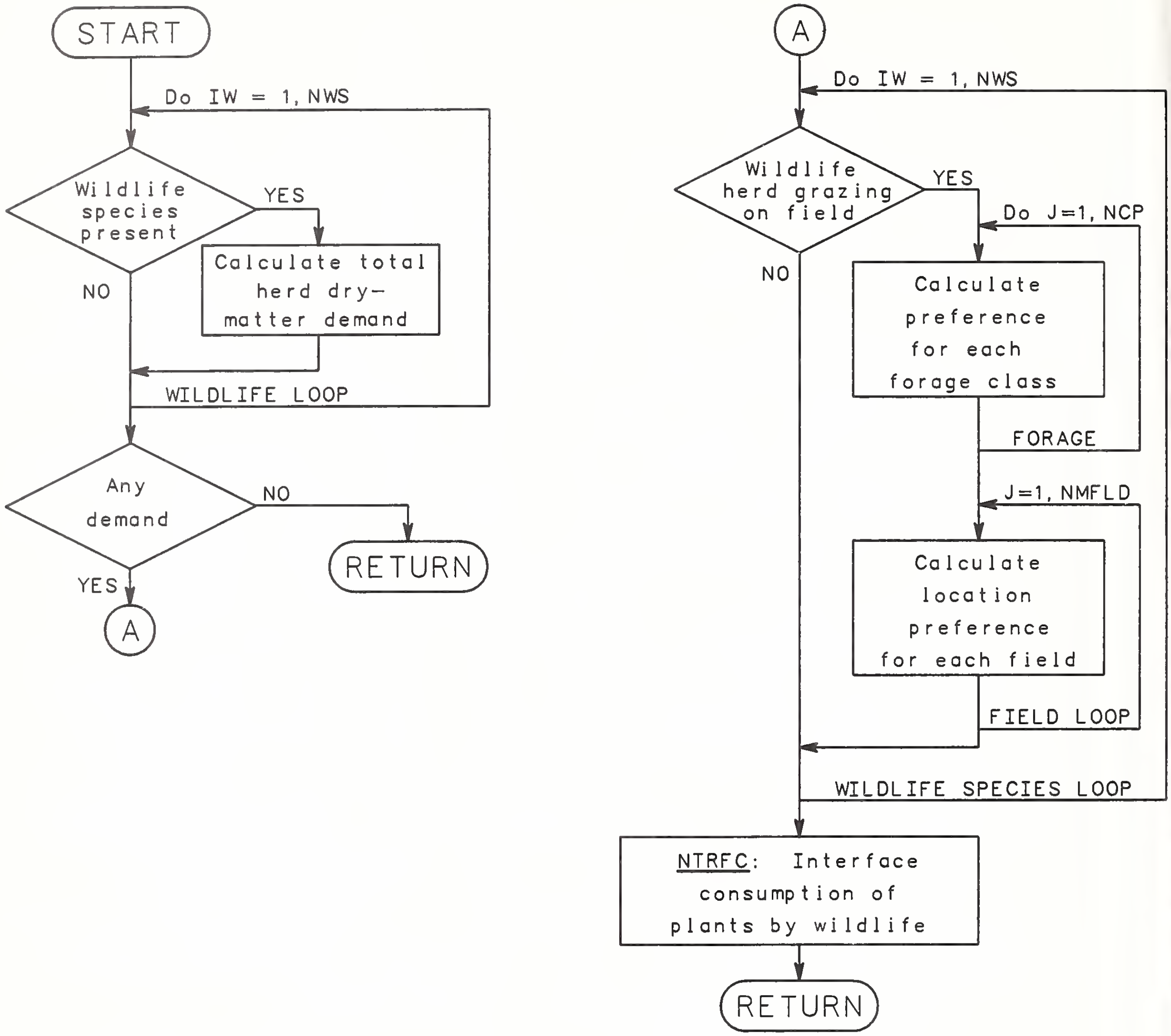


Figure 3.46
Subroutine WLDLF: Allow for consumption of plants by wildlife.

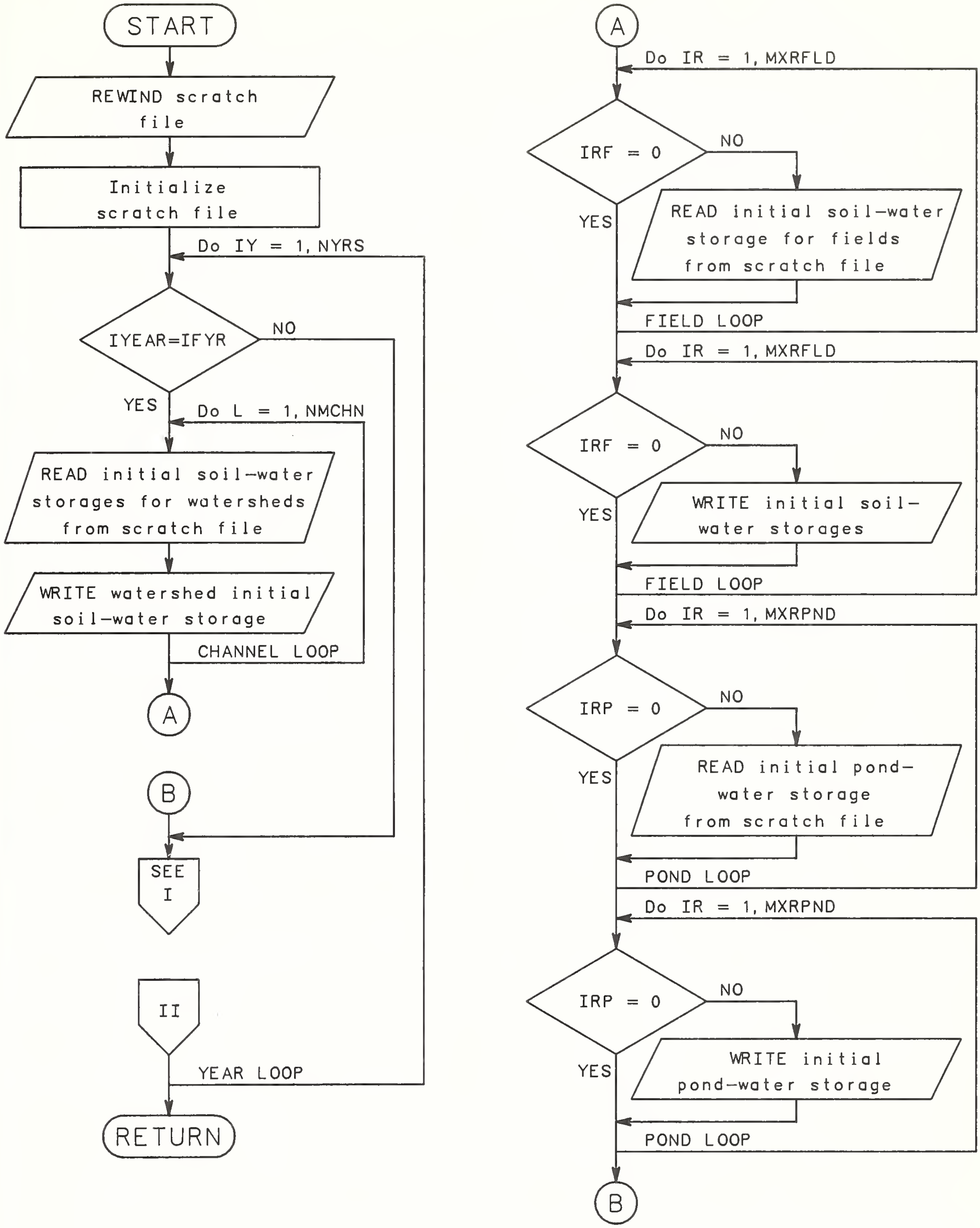


Figure 3.47
Subroutine YRSUM: Generate yearly report.

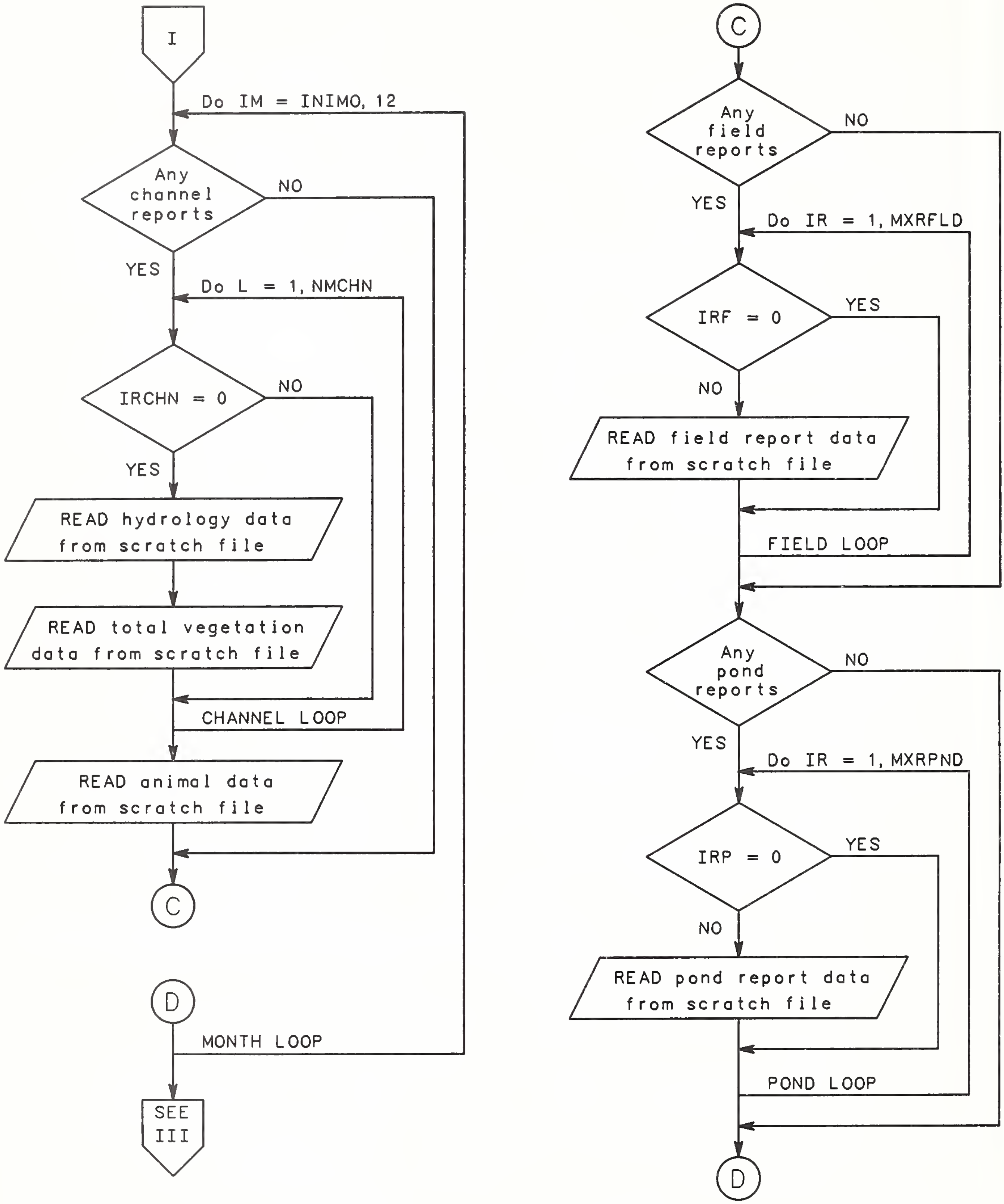


Figure 3.47--Continued
Subroutine YRSUM: Generate yearly report.

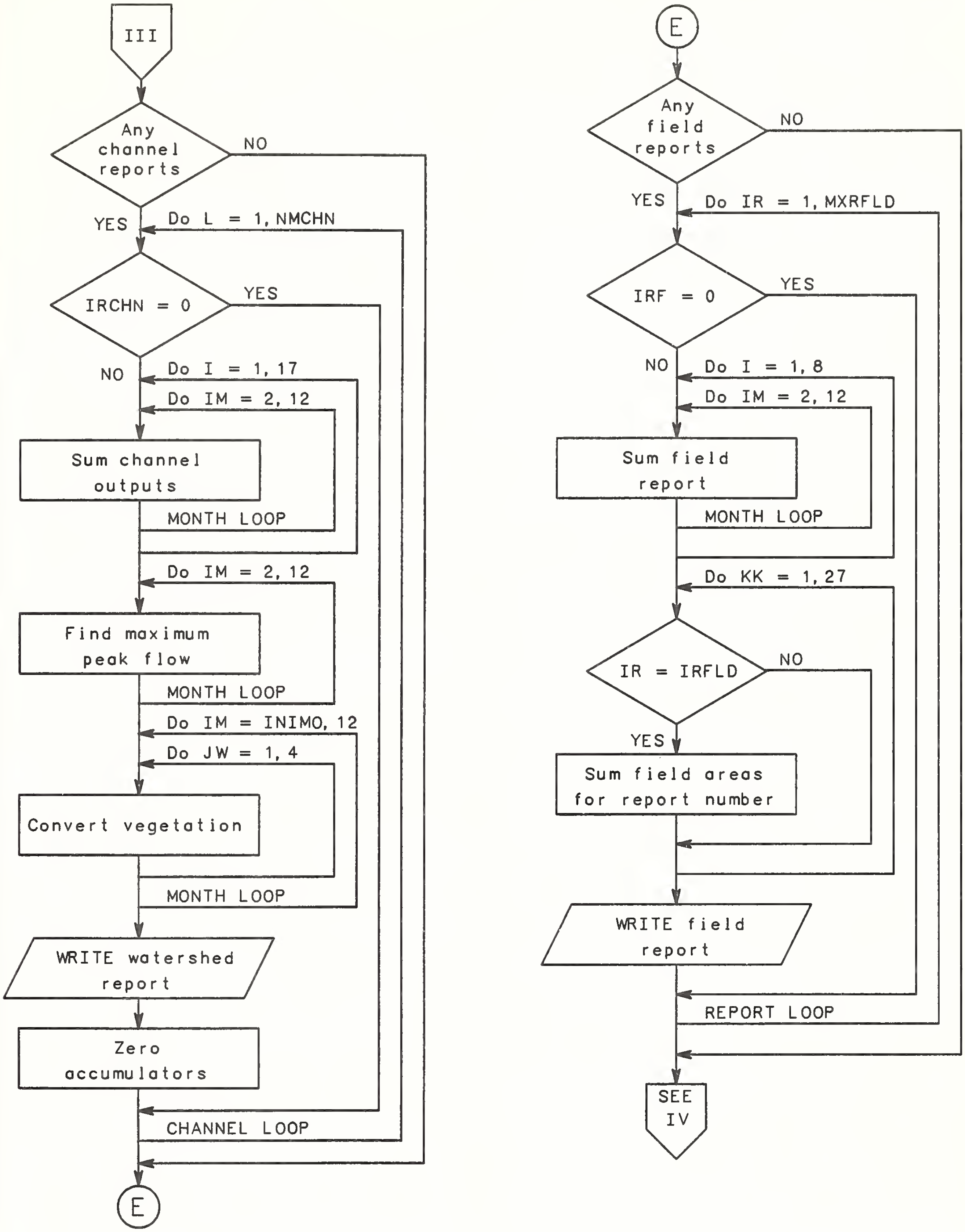
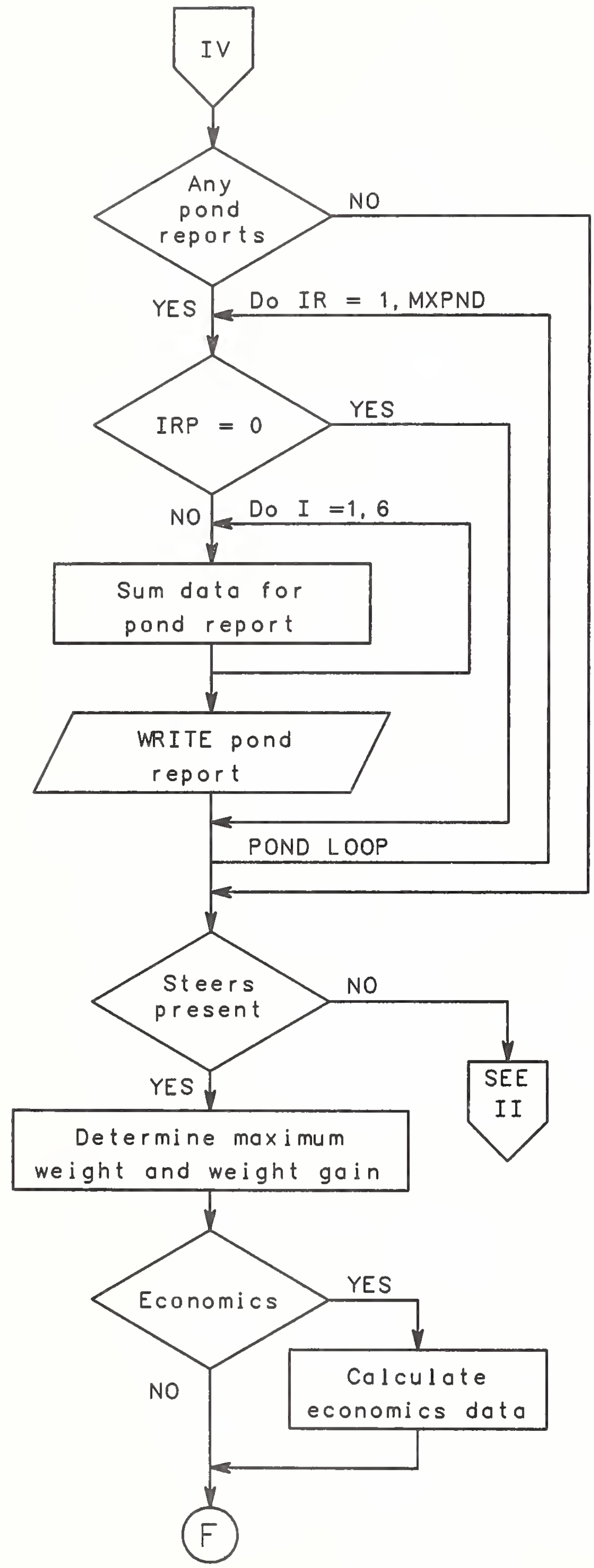


Figure 3.47--Continued
Subroutine YRSUM: Generate yearly report.



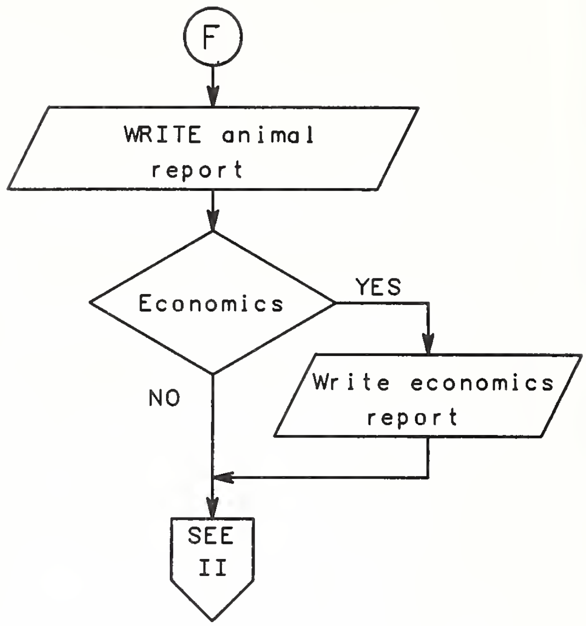


Figure 3.47--Continued
Subroutine YRSUM: Generate yearly report.

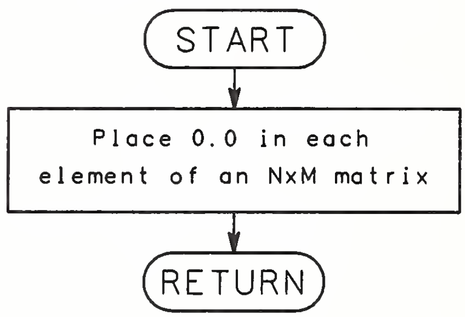


Figure 3.48
Subroutine ZERO: Zero an N by M matrix.

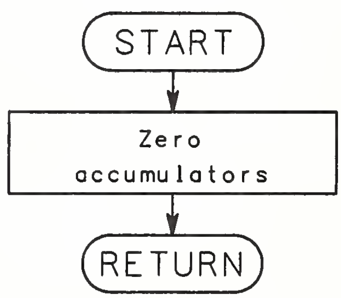


Figure 3.49
Subroutine ZERO19: Zero accumulators.

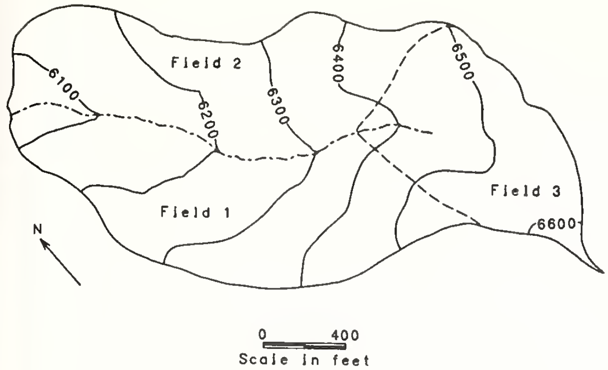


Figure 3.50
Topographic map with field site locations, Upper Sheep Creek Watershed.

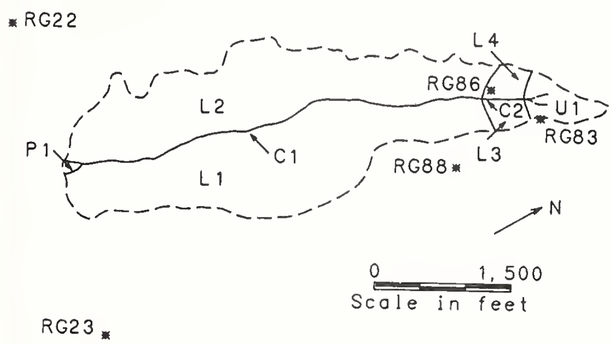


Figure 3.51
Lucky Hills Watershed used in the model evaluation showing two lateral areas (L1-L2), one upland area (U1), and a single channel reach (C1) draining into one pond (P1).

The number of years and channels to be simulated are set on record 2. The IRAIN variable indicates if precipitation input is to be read by fields. If IRAIN does not equal zero, the data for each field will be expected from the CLIMATE input file. Record 3 is the format for the daily weather data. The coefficients that describe the hydrograph for both channels and fields are entered on record 4.

Cards 5 to 9 hold information required for a channel. Channel ID number and input-channel(s) ID number(s) are entered on record 5. The channel report flag is set to 1 if a report is desired. Record 6 contains parameters for channel hydraulic response and sediment transport. The fraction of silt and clay (FSC) is the percentage of particles in the channel sediments less than 0.062 mm in diameter. If there are larger particles in the bed (NPC>0), the entries on records 7 and 8 describe the median particle diameter for a sediment-sized class (DI) and the percentage (decimal value) of the bed material that falls within the particle-sized class.

Ponds are described on record 9. If there are no ponds, all values on record 9 must have a zero entered or an error will result.

Records 10 to 17 contain information about the fields. These cards must be repeated for each field within a subbasin. The field-report flag on record 10 is set to a number between one and the maximum number of field reports (MXRFLD). Therefore, all fields with the report number 2 (IRFLD=2) will be compiled into a single field report. This allows users to lump field reports such as all lateral or upland fields or any combination. Record 11 contains the USLE parameters for the MUSLE calculations. Also, the slope (SLOPE) and aspect (ASPECT) are entered for each field. These are used to adjust incoming solar radiation for the slope and aspect of the field. Record 12 contains the variable STF which is the initial soil moisture content and represents a fraction of field capacity for the first day. The SPUR model (both versions) defines field capacity as the difference between the 1/3-bar and 50-bar water contents. The value of STF is a decimal value between 0.0 and 1.0, inclusive.

Records 13 to 17 hold the soil properties. The number of soil layers (NMSL) on Record 11 defines how many entries are required on Records 13 to 17. From table 3.3, the properties required are readily apparent. The 50-bar water content is calculated internally as these values are not generally available.

Record 17 has the thickness of each of the NMSL soil layers that are required. Two constraints have been incorporated for more reasonable execution of the program. First, the top two soil layers must sum to 6 inches (15 cm). It is advised to use two soil layers 3 inches (7.5 cm) thick, but any combination is possible. The reason for this constraint is that as water enters the soil, the water is assumed to wet the entire soil layer uniformly. In the model, soil-water tension is a function of soil-water content and at very high tensions (less than -15 bars), the amount of water required for rapid fluctuations in soil-water tension (from -40 bars to -20 bars, for example) is small. One of the controlling factors in the plant component of SPUR is the soil-water tension at 6 inches (15 cm).

It was found through experimenting with the computer program that small precipitation events caused dramatic responses in the plant component. Much of this effect was traced to the rapid fluctuation in soil-water tension. By creating two soil layers in the upper 6 inches (15 cm) of the profile, the effects of small precipitation events are minimized because the storage in the upper soil layer will accommodate most, if not all, of the incoming water. The user should also be cautioned that by turning on the crackflow routine, the benefit gained by using two soil layers is lost because crackflow by-passes the soil-water storage component. The second

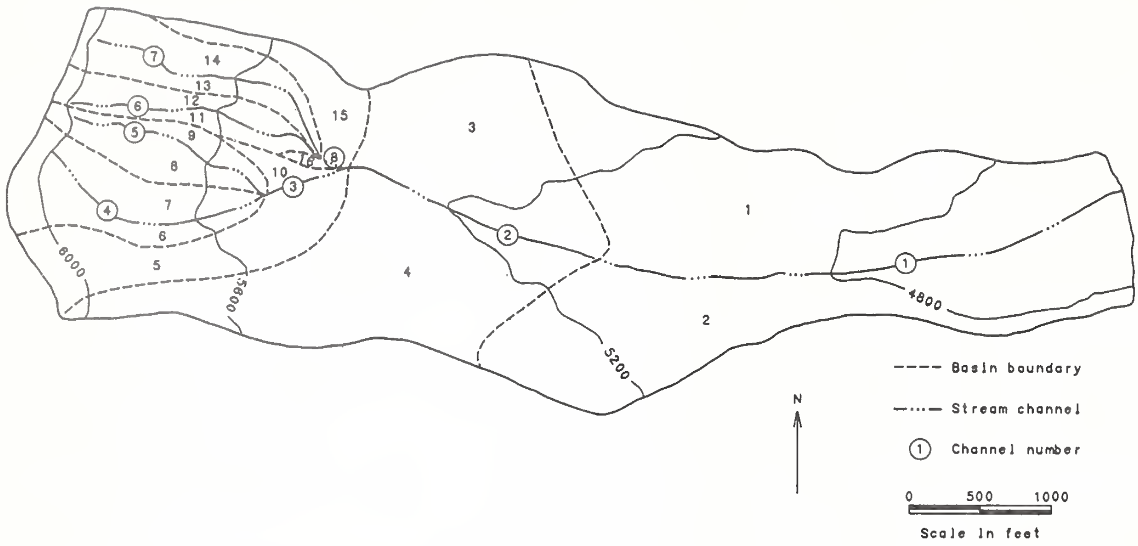


Figure 3.52
Topographic map with field site locations, Murphy Creek Watershed.

constraint is that the rooting depth must not be greater than the depth of the profile to the top of the last layer. Roots are not to be included in the last layer of the soil profile.

Record 18 provides more general site information. The latitude of the watershed in degrees is DLAT. The two remaining variables, SELE and TELE, are used to lapse air temperatures with a standard lapse rate of 6.5 °C/1000 m change in elevation. The variable SELE is the elevation of the watershed and TELE is the elevation of the temperature measurement station. Lapse rates are known to vary with season and inversions are common, but these are so site specific that we were not able to accommodate all the possibilities in the code. The function subprogram TLAPSE determines the lapsed temperature. All modifications in determining lapse rate can be made by changes in TLAPSE.

Records 19 through 21 are the snow accumulation and melt routines parameters and initial-condition cards. Snow processes are determined on a field-by-field basis, so cards 19 to 21 are repeated for each field in the order of input for the fields. The parameters are described in the documentation for the snow routines. The initial snow water equivalent is entered on record 21.

Again, the user is encouraged to study and run the sample problems and these procedures will become more apparent.

Climate Input File

Input order for the climate file follows the same format as for the field-scale version of SPUR. Input order is precipitation, maximum temperature, minimum temperature, solar radiation, and total wind run. An option in the basin-scale version will allow spatial distribution of precipitation to be input. By setting the IRAIN flag to 1 in record 2 and entering a value greater than zero for the daily precipitation value, a value for precipitation will be read for each field. These values need to be entered on cards following the daily climate data in the order that the fields were entered with a format of 8F10.5. On days when there is no precipitation, these records are not required.

Chapter 4 of Part II describes procedures for generating the climate file if observed data are not available.

The Plant-Component Input File

The plant component of the SPUR model is a general, deterministic set of equations and relationships that can simulate the dynamics of both cool-season (C_3) and warm-season (C_4) plants. The model processes each plant species in the simulation in exactly the same manner (with small exceptions for computational efficiency); all species growth, death, and physiological dynamics are calculated the same way, no matter whether the species is C_3 or C_4. To simulate the differences between plant species found on the rangeland (the species' responses to moisture, nutrients, and to abiotic variables), the user must supply a set of parameters and critical values for each plant species to be simulated. These parameters and critical values are used to distinguish the physiological and ecological differences between plants and they are in effect for the entire simulation. (See chapters 6 in both Part I and II.)

The plant component also controls the calculation of certain variables on the site being simulated. This part of the model is also general and deter-

Table 3.3
Simulation control and hydrology-component input for the Basin-scale version of SPUR

Record number	Format	Variable name and description
RECORD 1	(80A1)	WID- title of the simulation.
RECORD 2	(4I5,F10.4,I5,5I2)	
	I5	IFYR- first year of the simulation.
	I5	NYRS- number of years to simulate.
	I5	INIM- month simulation begins.
	I5	IDAY- day simulation begins.
	F10.4	AREA- total watershed area in square miles.
	I5	NMCHN- number of channel segments.
	I2	IRAIN- flag to indicate precipitation is to be read by fields.
	I2	KONVRT- convert temperatures and precipitation from metric to English units.
	I2	IP1- print flag for printing daily simulation results.
	I2	IP2- print flag for printing storm-day results.
	I2	IP3- print flag for printing monthly/annual results.
RECORD 3	(80A1)	FMT- format to read climate file.
RECORD 4	(8F10.5)	
	F10.5	C1- coefficient for area-storm duration relation (h/ac).
	F10.5	C2- exponent for area-storm duration relation.
	F10.5	C3- coefficient for area-storm runoff-volume relation (in/ac).
	F10.5	C4- exponent for the area-storm runoff volume relation.
	F10.5	C5- coefficient for the peak flow relation.
RECORD 5	(5I5,4F10.4/I5,6F10.4)	
	I5	IDCHN- channel number (1-9).
	I5	J1- number of upstream input channel.
	I5	J2- number of upstream input channel.
	I5	NMFLD- number of fields for subbasin.

Table 3.3--Continued
Simulation control and hydrology-component input for the Basin-scale version of SPUR

Record number	Format	Variable name and description
RECORD 5--Continued		
	I5	IRCHN- channel report flag; if 1 then report will be made for this channel; a value of zero, no report.
	F10.4	CHNL- channel length (mi).
	F10.4	CHNW- channel width (ft).
	F10.4	CHNWE- channel width at the outlet (ft).
	F10.4	CHNHC- channel hydraulic conductivity (in/h).
RECORD 6	(5I5,4F10.4/I5,6F10.4)	
	I5	NPC- number of particle-sized classes for sediment transport calculations (maximum of 10).
	F10.4	CHNSLP- channel slope (ft/ft).
	F10.4	XN- Manning's n value for total roughness.
	F10.4	XNW- Manning's n value for wall roughness.
	F10.4	D50- median particle size of the bed material (mm).
	F10.4	FSC- fraction of silt and clay in bed material (decimal fraction).
	F10.4	CAS- reciprocal of silt-clay settling velocity (s/ft).
******************** OMIT RECORDS #07 AND #08 IF NPC = 0 ***************		
RECORD 7	(10F8.4)	DI- median diameter of bed material in particle-sized class (mm); enter number of sizes equal to NPC.
RECORD 8	(10F8.4)	FI- percentage of bed material in particle size class; decimal values, enter in order relative to diameters in RECORD 7.
RECORD 9	(2I5,4F10.4)	
	I5	IDPND- pond number.
	I5	IRPND- pond report printed when set to 1.
	F10.4	PNDFA- pond area when pond is full (acres).
	F10.4	PNDFV- pond volume when full (ac-ft).

Table 3.3--Continued
Simulation control and hydrology-component input for the Basin-scale version of SPUR

Record number	Format	Variable name and description
RECORD 9--Continued		
	F10.4	PNDV- pond volume at start of simulation (ac-ft).
	F10.4	PNDHC- hydraulic conductivity of material on pond bottom (in/h).
**************** REPEAT RECORDS #10 THROUGH #17 FOR EACH FIELD *******		
RECORD 10	(4I5,3F10.4/8F10.4/3F10.5)	
	I5	IDFLD- field number.
	I5	ITFLD- field type; if set to zero, upland field; if set to 1, lateral field.
	I5	NMSL- number of soil layers for the field (maximum of 8).
	I5	IRFLD- field-report flag; if set to 1 a report will be printed.
	F10.4	FLDA- field area (acres).
	F10.4	S1- condition I curve number.
	F10.4	S2- return-flow travel time (days).
RECORD 11	(4I5,3F10.4/8F10.4/3F10.5)	
	F10.4	FLDK- USLE K factor.
	F10.4	FLDC- USLE C or cover factor.
	F10.4	FLDP- USLE P or practice factor.
	F10.4	FLDLS- USLE slope-length factor.
	F10.4	RD- rooting depth (inches).
	F10.4	SLOPE- slope of field for solar radiation adjustment (ft/ft).
	F10.4	ASPECT- aspect of field for solar radiation adjustment (azimuth in degrees).
	F10.4	CONA- soil evaporation parameter for ET (in/d**0.5).
RECORD 12	(4I5,3F10.4/8F10.4/3F10.5)	
	F10.5	CF- crack factor for crack-flow calculations (decimal fraction).
	F10.5	STF- fraction of field capacity in initial soil moisture (decimal fraction).
	F10.5	GR- mulch (residue) cover factor.

Table 3.3--Continued
Simulation control and hydrology-component input for the Basin-scale version of SPUR

Record number	Format	Variable name and description
RECORD 13	(8F10.4)	SMO- porosity of soil layer; enter NMSL values (maximum of 8).
RECORD 14	(8F10.4)	SM3- 1/3-bar volumetric water content for layer; enter NMSL values (maximum of 8).
RECORD 15	(8F10.4)	SM15- 15-bar volumetric water content for layer; enter NMSL values (maximum of 8).
RECORD 16	(8F10.4)	SLSC- saturated soil-hydraulic conductivity for layer; enter NMSL values (maximum of 8, in/h).
RECORD 17	(8F10.4)	SLDTH- thickness of soil layer (inches); enter NMSL values (maximum of 8); same as THK in Part I.
RECORD 18	(8F10.5)	
	F10.5	DLAT- latitude of the watershed (degrees).
	F10.5	SELE- elevation of the watershed (ft).
	F10.5	TELE- elevation of the temperature measurement station (ft).
RECORD 19	(8F10.5)	
	F10.5	SCF- snow gauge-catch correction factor.
	F10.5	MFMAX- maximum melt factor for nonrain periods (mm/day-°C).
	F10.5	MFMIN- minimum melt factor for nonrain periods (mm/day-°C).
	F10.5	UADJ- wind adjustment factor for rain-on-snow periods (mm/mb/h).
	F10.5	SI- maximum accumulated snow water equivalent above which there is 100 percent snow cover (mm).
	F10.5	ADPT- areal depletion curve type number, values range between 1 and 6 with fractional values interpolated.
	F10.5	NMF- maximum negative melt factor (mm/°C).
	F10.5	TIPM- weight applied to preceding-period temperature to calculate current snowpack temperature in the range 0.0 to 1.0.

Table 3.3--Continued
Simulation control and hydrology-component input for the Basin-scale version of SPUR

Record number	Format	Variable name and description
RECORD 20	(8F10.5)	
	F10.5	MBASE- temperature for nonrain melt (°C).
	F10.5	PXTEMP- temperature to differentiate rain from snow (°C).
	F10.5	PLWHC- liquid-water holding capacity of the snowpack; in the range 0.0 to 1.0.
	F10.5	DAYGM- constant daily melt at snow-soil interface (mm).
RECORD 21	(8F10.5)	FLDWE- field snow water equivalent at the start of the simulation (mm).

ministic. Such information as soil-inorganic nitrogen concentration and accumulated litter is calculated in the plant-component submodel.

A maximum of seven plant species may be included in any one simulation. The user may not have seven plant species on one field and seven plant species on another, and so forth. Rather, only seven plant species may be used over the entire watershed. The user-supplied parameters and critical values for each species are used for all fields on the simulated watershed.

A maximum of 27 fields may be included in any one simulation. A minimum of three fields is required for each simulation. For each field, the user must supply the starting levels in four state variables per simulated plant species. These constitute the beginning phytomass compartments for each species and are stored in the two-dimensional array PHYTM. Again, the user must supply these four-state-variable levels on a per-field basis.

Additionally, the user must supply field-specific (but not species-specific) variables for each field. These are the beginning values for soil inorganic matter (SNIO), dead roots (DROOTS), accumulated litter (ALIT), and soil organic matter.

Also, six variables that are neither species-specfic nor field-specific must be supplied. These variables (the vector PNS) control the rates of decomposition and are assumed to be independent of plant species or field(s) on the watershed.

Table 3.4 lists the variables, the format, and the description for each record in the plant-component input file.

The Animal-Component Input File

The SPUR model has the capability to simulate the effects of grazing by wild as well as domestic animals. Using a set of equations and relationships, the model can also simulate the physiological growth of a steer and then multiply that information by the size of the herd of grazing steers to establish herd weight gain or loss and the (fixed) economic return therefrom.

Wildlife

The first record read from the animal-component initialization file is the number of wildlife species (NWS) to be used in the simulation experiment. A maximum of 10 wildlife species may be used in any one experiment. If the number of wildlife species is zero, the program skips the remaining wildlife-parameter read statements and begins reading information for the domestic grazing animals.

If one or more wildlife species present, the user then must supply the size of the herds of each wildlife species (POPSZ). The user then indicates the preference for location (PLOC) of each wildlife species, 1.0 being equivalent to 100 percent preference and zero being no preference for a field. A preference for each field must be specified for each wildlife species. Also, all preferences for location must sum to 1.0 for each wildlife species.

The user then specifies the preference of each wildlife species for each forage class (PREF). A class here is defined as either standing green biomass or standing dead biomass of a simulated plant species. Thus, if 7 plant species or functional groups are being used in a simulation

Table 3.4
Plant-component input for the basin-scale version of SPUR

Record number	Format	Variable name and description
RECORD 1	(5I5,2F10.5,2I5)	
	I5	NSPEC- number of plant species.
	I5	NPARAM- number of parameters per plant species.
	I5	NCRITS- number of critical values per plant species.
RECORDS 2-8	(A80)	ASPEC- species name (one RECORD per species to a maximum of NSPEC).
RECORD 9	(8F10.5)	$P_{1,S}$- theoretical maximum net photosynthetic rate (mg dm^{-2} h^{-1}).
RECORD 10	(8F10.5)	$P_{2,S}$- light-use efficiency coefficient (m^2 w^{-1}).
RECORD 11	(8F10.5)	$P_{3,S}$- maximum temperature for positive plant activity (°C).
RECORD 12	(8F10.5)	$P_{4,S}$- optimum temperature for positive plant activity (°C).
RECORD 13	(8F10.5)	$P_{5,S}$- minimum temperature for positive plant activity (°C).
RECORD 14	(8F10.5)	$P_{6,S}$- photosynthetic-activity water potential (-bars).
RECORD 15	(8F10.5)	$P_{7,S}$- drought-tolerance coefficient (dimensionless).
RECORD 16	(8F10.5)	$P_{8,S}$- proportion of photosynthate sent to roots (dimensionless).
RECORD 17	(8F10.5)	$P_{9,S}$- maximum root-to-shoot ratio (dimensionless).
RECORD 18	(8F10.5)	$P_{10,S}$- wind-tolerance coefficient (km^{-1}).
RECORD 19	(8F10.5)	$P_{11,S}$- precipitation-tolerance coefficient (cm^{-1}).
RECORD 20	(8F10.5)	$P_{12,S}$- proportion of phytomass susceptible trampling (dimensionless).
RECORD 21	(8F10.5)	$P_{13,S}$- susceptibility of standing dead to trampling (ha an^{-1}).
RECORD 22	(8F10.5)	$P_{14,S}$- susceptibility of green shoots to trampling (ha an^{-1}).
RECORD 23	(8F10.5)	$P_{15,S}$- proportion green shoots susceptible to death (dimensionless).
RECORD 24	(8F10.5)	$P_{16,S}$- phytomass conversion factor (m^2 g^{-1}).

Table 3.4--Continued
Plant-component input for the basin-scale version of SPUR

Record number	Format	Variable name and description
RECORD 25	(8F10.5)	$P_{17,S}$- proportion of photosynthate sent to propagules (dimensionless).
RECORD 26	(8F10.5)	$P_{18,S}$- proportion for translocation from roots to shoots (TRS) (dimensionless).
RECORD 27	(8F10.5)	$P_{19,S}$- germination proportion (dimensionless).
RECORD 28	(8F10.5)	$P_{20,S}$- maintenance-respiration coefficient (mg g^{-1} day^{-1}).
RECORD 29	(8F10.5)	$P_{21,S}$- proportion additional shoot death after senescence (dimensionless).
RECORD 30	(8F10.5)	$P_{22,S}$- NOT USED.
RECORD 31	(8F10.5)	$P_{23,S}$- seed-mortality proportion (dimensionless).
RECORD 32	(8F10.5)	$P_{24,S}$- root-respiration proportion (dimensionless).
RECORD 33	(8F10.5)	$P_{25,S}$- root-mortality proportion (dimensionless).
RECORD 34	(8F10.5)	$P_{26,S}$- minimum percent nitrogen for photosynthesis (dimensionless).
RECORD 35	(8F10.5)	$P_{27,S}$- photosynthetic efficiency controlled by nitrogen (dimensionless).
RECORD 36	(8F10.5)	$P_{28,S}$- maximum-nitrogen-uptake coefficient (g N g^{-1} day^{-1}).
RECORD 37	(8F10.5)	$P_{29,S}$- nitrogen-use efficiency coefficient (m^2 g^{-1}).
RECORD 38	(8F10.5)	$CRIT_{1,S}$- maximum leaf area of green shoots (dimensionless).
RECORD 39	(8F10.5)	$CRIT_{2,S}$- temperature for frost kill (°C).
RECORD 40	(8F10.5)	$CRIT_{3,S}$- temperature for TRS (°C).
RECORD 41	(8F10.5)	$CRIT_{4,S}$- water potential for TRS (bars).
RECORD 42	(8F10.5)	$CRIT_{5,S}$- water potential for seed germination (bars).
RECORD 43	(8F10.5)	$CRIT_{6,S}$- day that seed production begins (dimensionless).
RECORD 44	(8F10.5)	$CRIT_{7,S}$- day that senescence begins (dimensionless).
RECORD 45	(8F10.5)	$CRIT_{8,S}$- day that senescence ends (dimensionless).

Table 3.4--Continued
Plant-component input for the basin-scale version of SPUR

Record number	Format	Variable name and description
************** RECORDS 46 THROUGH 50 TO BE REPEATED FOR EACH SITE ***		
RECORD 46	(8F10.5)	
	F10.5	SNIO- soil inorganic nitrogen ($g\ m^{-2}$).
	F10.5	DROOTS- dead roots ($g\ m^{-2}$).
	F10.5	ALIT- litter ($g\ m^{-2}$).
	F10.5	AORG- soil organic matter ($g\ m^{-2}$).
RECORD 47	(8F10.5)	$PHYTM_{1,S}$- standing green phytomass ($g\ m^{-2}$).
RECORD 48	(8F10.5)	$PHYTM_{2,S}$- live root phytomass ($g\ m^{-2}$).
RECORD 49	(8F10.5)	$PHYTM_{3,S}$- propagule phytomass ($g\ m^{-2}$).
RECORD 50	(8F10.5)	$PHYTM_{4,S}$- standing dead phytomass ($g\ m^{-2}$).
RECORD 51	(8F10.5)	
	F10.5	PNS_1- proportion dead roots susceptable to decomposition (dimensionless).
	F10.5	PNS_2- proportion litter susceptable to decomposition (dimensionless).
	F10.5	PNS_3- proportion organic matter susceptable to decomposition (dimensionless).
	F10.5	PNS_4- moisture tolerance of denitrification (-bars).
	F10.5	PNS_5- decomposition water potential (-bars).
	F10.5	PNS_6- drought-tolerance coefficient for decomposition (dimensionless).

experiment, a total of 14 forage classes would be available for wildlife consumption. Again, a value of 1.0 indicates a 100 percent preference for forage class, while a zero indicates no preference for a forage class. A preference for each forage class by each wildlife species must be supplied. Also, the preferences expressed by each wildlife species for all forage classes must sum to 1.

Next, the user specifies the Julian day on which each wildlife species arrives at the watershed (TIN) and the Julian day on which it departs (TOUT). (See the discussion of Errors 76 and 77 in chapter 9 for the limitations on these two variables.)

The final wildlife initial variable the user must supply is the dry-matter intake (DMI) for one member of each wildlife species (or herd). This feature allows the use of organisms with large population sizes but relatively small daily forage requirements (for example, rodents) to harvest the forage, as well as allowing use by larger animals (for example, pronghorn antelope) which have greater forage requirements but relatively smaller

population sizes.

Note that SPUR does not physiologically grow wildlife species. Rather, the model uses wildlife as a sink for the removal of vegetation. Also, only standing green biomass and standing dead biomass are considered to be forage available for harvest by wildlife. No mechanism exists in the model for the removal of seeds from a site by granivorous rodents or insects.

Domestic Animals

The SPUR model contains the formulations required to physiologically add to or subtract from adipose tissue to a simulated growing steer. Other domestic animals which are typically allowed to graze rangeland are not included in the formulations. If the user wishes to graze sheep, for example, he or she must convert the body weight of a sheep to the body weight of a steer to get a sort of steer equivalent. So, suppose the user wants to graze 50 sheep and that one steer weighs about the same as 5 sheep. The user then enters the number of domestic grazing animals as 10. The user must also realize that the results for the simulation do not reflect the growth of the sheep but are for steer-equivalent animals. The user supplied preference vectors should reflect grazing habits of sheep.

The SPUR program requires an input value for the number of steers (NUM) to be used in the simulation experiment. If this value is zero, the remainder of the read statements for the steer initial conditions are not executed. If steers are present for the simulation, the program reads a flag (ISUP) indicating whether the steer diet is to be supplemented. Next, the user supplies the asymptotic weight of a mature steer of the breed being simulated (WMA), the Julian day the steer herd is to begin grazing (TINS), the Julian day on which the animals are removed from the field (TOUTS), the weight of an average steer on the day the herd begins grazing (WT), and the age in Julian days of the average steer on the day the herd begins grazing (TAVG).

Next, if the supplementation flag is given a value of 1, the user must supply the amount of the supplement in kilograms (SUP), the digestibility of the supplement (DIGS), and the Julian days when the supplementation begins (TS1) and ends (TS2). If the diet supplementation flag is not turned on, then omit this information.

The user next provides the preference of the steer for each forage class, all preferences summing to 1.0 (vector A1). Then, the physical limitation for each forage class must be supplied (vector A2). Also, preference for each field must be supplied (vector A3), and the physical limitations for access to each field must be supplied (vector A4). The user is directed to the discussion of the possible errors that may be generated for the steer initialization component in chapter 9.

The brief amount of information needed to run the economics of the simulated rangeland is required next. First, the economics flag (ICON) must be set to 1. If it is not, the remainder of the information is not read. The next record holds the price per weight class of steers (vector PRICE). The final record supplies the discount rate (DRATE) and the costs (COSTS). If no steers are grazed, no economic information is calculated.

Table 3.5 lists the variables, the format, and the description for each record in the animal-component initialization file.

SPUR OUTPUT FILE

The basin-scale version of SPUR has the capability to produce three temporal reports: daily, storm-day, and monthly/annual summaries. These reports are controlled by print flags IP1, IP2, and IP3 which are described in table 3.3. Spatial resolution of the reports is controlled by report flags for fields and each channel or subbasin. A maximum of 27 fields can be used in any simulation, but the user is cautioned that allocating file storage for all possible fields will result in considerable overhead. Therefore, 5 field reports can be generated utilizing any combination of the 27 possible fields. All output is written to the file SUMARY.DAT on LUN 16.

As each report is discussed, it should be remembered that more detailed reports can be obtained from SPUR, and users should not be limited by what was considered pertinent in model development. With knowledge of FORTRAN programing techniques, the dictionaries in the program listing, and this User Guide, the output stream can be altered to produce the desired reports.

Daily Option

Figure 3.53 is an example of the daily-report option for the watershed in figure 3.51. This frequency of reporting requires an extensive amount of disk storage for output and scratch files. A user should carefully consider storage requirements before requesting this option.

The daily report is organized into field or upland reports, a pond report, and channel reports for each channel system. A list of the output labels found in figure 3.53 is presented in Table 3.6.

Storm-Day Option

Figure 3.54 is an example of storm-day output. This report is designed primarily for hydrologic analysis as evidenced by the lack of plant and animal variables in the report. These reports are for channels only and are not generated for fields.

Monthly/Annual Option

The final option is the monthly/annual summary, an example of which is given in figure 3.55. These reports are produced for channels and fields and ponds and have the most utility for long-term simulations. Table 3.7 lists the labels for this report.

Table 3.5
Animal-component input for the basin-scale version of SPUR

Record number	Format	Variable name and description
RECORD 1	(I5)	NWS- Number of wildlife (maximum of 10).
******************** OMIT RECORDS 2 THROUGH 6 IF NWS = 0 ******************		
RECORD 2	(10F8.5)	POPSZ- population size of each wildlife herd (one per NWS).
RECORD 3	(8F10.5)	PLOC- location preference per wildlife herd per site.
RECORD 4	(8F10.5)	PREF- preference for live and dead forage per wildlife herd.
RECORD 5	(8F10.5)	
	F10.5	TIN- date each wildlife herd begins to graze.
	F10.5	TOUT- date each wildlife herd stops grazing.
RECORD 6	(8F10.5)	DMI- daily-dry matter intake per single member of the wildlife herd (kg).
RECORD 7	(I5)	NUM- number of steers.
******************* OMIT RECORDS 8 THROUGH 17 IF NUM = 0 ******************		
RECORD 8	(I5)	ISUP- steer diet supplement flag.
RECORD 9	(8F10.5)	
	F10.5	WMA- mean asymptotic weight for a mature steer (kg).
	F10.5	TINS- day that grazing starts.
	F10.5	TOUTS- day that grazing ends.
	F10.5	TAVG- age of steer on TINS (day).
	F10.5	WT- weight of steer on TINS (kg).
*********************** OMIT RECORD 10 IF ISUP = 0 ************************		
RECORD 10	(8F10.5)	
	F10.5	SUP- amount of diet supplement (kg).
	F10.5	DIGS- digestibility of supplement.
	F10.5	TS1- day to start supplementing.
	F10.5	TS2- day to end supplementing.
RECORD 11	(8F10.5)	A1- steer preference vector for forage (live/dead).
RECORD 12	(8F10.5)	A2- steer limitation vector for forage.

Table 3.5--Continued
Animal-component input for the basin-scale version of SPUR

Record number	Format	Variable name and description
RECORD 13	(8F10.5)	A3- steer preference vector for site.
RECORD 14	(8F10.5)	A4- steer limitation vector for site.
RECORD 15	(I5)	ICON- economics calculation and report flag.
************** OMIT RECORDS 16 AND 17 IF NUM = 0 OR IF ICON = 0 **************		
RECORD 16	(8F10.5)	PRICE- price per weight class (dollars per 100 pounds).
RECORD 17	(8F10.5)	
	F10.5	DRATE- discount rate.
	F10.5	COSTS- cost per head per month (dollars).

Livestock and Economics Reports

If livestock grazing is simulated, a report for the entire watershed is created. Figure 3.56 is an example of the livestock report. The report breaks the grazing season into months and reports the number of days the cattle were grazing during that month and the weight of an average steer on the last day of the month. The final total under the year column is the weight gain for the year (final weight minus initial weight).

An economics report will be created for each year if such a report is requested. Figure 3.57 is an example of the economics report. Headings for this report are self-explanatory, and the methods used to calculate these values are in Part I, "Documentation."

LITERATURE CITED

Springer, E.P., C.W. Johnson, K.R. Cooley, and D.C. Robertson. 1984. Testing the SPUR hydrology component on rangeland watersheds in southwest Idaho. Transactions of the American Society of Agricultural Engineers 27: 1040-1046, 1054.

Table 3.6
List of labels in the daily-output report and their descriptors for the basin-scale version of SPUR

Label	Units	Description
RAIN	IN	Precipitation on field.
INFIL	IN	Total infiltrated water.
CN		Curve number for the field and initial water content.
Q	IN	Surface runoff.
QP	FT^3/S	Peakflow rate for Q.
TQ	IN	Total runoff volume (surface + return flow).
TQP	FT^3/S	Peak flow rate for TQ.
ES	IN	Actual soil evaporation.
EP	IN	Actual plant transpiration.
WBRZ	IN	Water percolation below the root zone.
WOUT	IN	Water percolation out of the soil profile.
SSF	IN	Subsurface return flow.
STORAGE	IN	Available water stored in the soil profile.
SED	TON	Upland soil loss by MUSLE.
FLDWE	IN	Snow water equivalent.
LIVE VEG	G/M^2	Aboveground live vegetation.
DEAD VEG	G/M^2	Aboveground dead vegetation.
QUP	IN	Inflow to channel from upland fields.
QLAT	IN	Inflow to channel from lateral fields.
LOSSES	IN	Transmission losses for the channel.
Q	IN	Total runoff from the subbasin.
QP	FT^3/S	Peak flow rate for the subbasin.
SUS	TON	Suspended sediment yield for subbasin.
BED	TON	Bed load sediment yield for subbasin.
PNDR	AC-FT	Rainfall on pond.
PNDEV	AC-FT	Evaporation from pond.
PNDS	AC-FT	Seepage from pond.
Q	AC-FT	Discharge from pond.
QP	FT^3/S	Peak flow rate adjusted for pond.
PNDV	AC-FT	Current pond volume.

Table 3.7
List of labels in the monthly/annual report summary and their descriptions for the basin-scale version of SPUR

Label	Units	Description
RAINFALL	IN	Precipitation input.
INFILTR	IN	Amount of infiltrated water.
RUNOFF	IN	Surface runoff.
RTN FL		Subsurface return flow.
SOIL EVAP	IN	Soil water evaporated.
PLANT EVAP	IN	Soil water transpired.
DEEP PERC	IN	Water percolated below root zone.
STORAGE	IN	Available water stored in the root zone.
PONDS:		
RAINFALL	AC-FT	Rainfall on the pond.
INFLOW	AC-FT	Inflow of channel water to the pond.
OUTFLOW	AC-FT	Outflow of water from pond.
EVAP	AC-ET	Evaporation of water from the pond.
SEEPAGE	AC-FT	Seepage of water from pond.
STORAGE	AC-FT	Pond storage on last day of the month.
CHANNELS:		
LOSSES	IN	Transmission losses.
RUNOFF	IN	Total runoff from subbasin (surface + return flow - losses).
PEAK	FT^3/S	Peak flow rate for channel.
BASIN WE	IN	Snow water equivalent for subbasin on last day of the month.
LIVE VEG	KG/HA	Total aboveground live vegetation on the last day of the month.
DEAD VEG	KG/HA	Total aboveground dead vegetation on the last day of the month.
SEDIMENT:		
FIELD SED	TON	Upland sediment yield from MUSLE.
SILT-CLAY	TON	Suspended sediment yield for subbasin.
BEDLOAD	TON	Bed load sediment yield for subbasin.

```
TEMPERATURE/RADIATION FOR DAY 234

MAX TEMP:    91.09691
MIN TEMP:    65.29419
SOLR RAD:   368.33160

FIELD DETAILS FOR CHANNEL  1  ON DAY 234(WATER:IN,PEAK:CFS, SEDIMENT:TONS, PONDS:AC-FT, VEGETATION:GM/M**2)
FIELD   RAIN  INFIL    CN       Q        QP       TQ       TPQ      ES      EP     WBRZ    WOUT     SSF   STORAGE    SED   FLDWE
    1  0.653  0.598  86.003   0.055    0.682    0.055    0.682   0.062   0.008   0.000   0.000   0.000   0.529   0.047   0.000
                                                                                          LIVE VEG        DEAD VEG
   WARM SEASON GRASSES                                                                     3.64794        13.38179
   COOL SEASON GRASSES                                                                     0.29299         3.82533
   WARM SEASON FORBS                                                                       0.79672         1.13338
   COOL SEASON FORBS                                                                       0.12556         0.75592
   SHRUBS                                                                                  4.84478        31.30676
FIELD   RAIN  INFIL    CN       Q        QP       TQ       TPQ      ES      EP     WBRZ    WOUT     SSF   STORAGE    SED   FLDWE
    2  0.653  0.598  86.003   0.055    0.613    0.055    0.613   0.062   0.008   0.000   0.000   0.000   0.529   0.106   0.000
                                                                                          LIVE VEG        DEAD VEG
   WARM SEASON GRASSES                                                                     3.64794        13.38179
   COOL SEASON GRASSES                                                                     0.29299         3.82533
   WARM SEASON FORBS                                                                       0.79672         1.13338
   COOL SEASON FORBS                                                                       0.12556         0.75592
   SHRUBS                                                                                  4.84478        31.30676
FIELD   RAIN  INFIL    CN       Q        QP       TQ       TPQ      ES      EP     WBRZ    WOUT     SSF   STORAGE    SED   FLDWE
    3  0.653  0.598  86.003   0.055    0.665    0.055    0.665   0.062   0.008   0.000   0.000   0.000   0.529   0.045   0.000
                                                                                          LIVE VEG        DEAD VEG
   WARM SEASON GRASSES                                                                     3.64794        13.38179
   COOL SEASON GRASSES                                                                     0.29299         3.82533
   WARM SEASON FORBS                                                                       0.79672         1.13338
   COOL SEASON FORBS                                                                       0.12556         0.75592
   SHRUBS                                                                                  4.84478        31.30676

CHANNEL DETAILS:     QUP      QLAT     LOSSES      Q        QP       SUS      BED
                    0.0193   0.0355   0.0015   0.0533   5.5714   0.3318   0.5395

FIELD DETAILS FOR CHANNEL  2  ON DAY 234(WATER:IN,PEAK:CFS, SEDIMENT:TONS, PONDS:AC-FT, VEGETATION:GM/M**2)
FIELD   RAIN  INFIL    CN       Q        QP       TQ       TPQ      ES      EP     WBRZ    WOUT     SSF   STORAGE    SED   FLDWE
    4  0.653  0.598  86.003   0.055    6.070    0.055    6.070   0.062   0.008   0.000   0.000   0.000   0.529   1.912   0.000
                                                                                          LIVE VEG        DEAD VEG
   WARM SEASON GRASSES                                                                     3.64794        13.38179
   COOL SEASON GRASSES                                                                     0.29299         3.82533
   WARM SEASON FORBS                                                                       0.79672         1.13338
   COOL SEASON FORBS                                                                       0.12556         0.75592
   SHRUBS                                                                                  4.84478        31.30676
FIELD   RAIN  INFIL    CN       Q        QP       TQ       TPQ      ES      EP     WBRZ    WOUT     SSF   STORAGE    SED   FLDWE
    5  0.653  0.598  86.003   0.055    6.119    0.055    6.119   0.062   0.008   0.000   0.000   0.000   0.529   0.743   0.000
                                                                                          LIVE VEG        DEAD VEG
   WARM SEASON GRASSES                                                                     3.64794        13.38179
   COOL SEASON GRASSES                                                                     0.29299         3.82533
   WARM SEASON FORBS                                                                       0.79672         1.13338
   COOL SEASON FORBS                                                                       0.12556         0.75592
   SHRUBS                                                                                  4.84478        31.30676

CHANNEL DETAILS:     QUP      QLAT     LOSSES      Q        QP       SUS      BED
                    0.0045   0.0501   0.0042   0.0504  38.1683   1.5425   5.4572
```

Figure 3.53
Example of daily output report from the basin-scale version of SPUR.

****** STORM 35 DAY 234

SUBBASIN SUMMARY FOR STORM DAY 234 (WATER:IN PEAK RATE:CFS SEDIMENT:TON PONDS:AC-FT)

CHANNEL ID	1	2
RAINFALL ON FIELDS	0.6527	0.6527
INFILTRATION	0.5979	0.5979
SURFACE RUNOFF	0.0548	0.0548
RETURN FLOW	0.0000	0.0000
CHANNEL LOSSES	0.0015	0.0043
SUBBASIN RUNOFF	0.0404	0.4538
SUBBASIN PEAK RATE	5.5714	38.1683
SUBBASIN CURVE NO.	85.8768	85.6332
FIELD SEDIMENT	0.1985	2.8536
CHAN SUSPENDED SED	0.3318	1.5425
CHAN BEDLOAD	0.5395	5.4572
BASIN SNOW WATER	0.0000	0.0000

Figure 3.54
Example of storm day output report from the basin-scale version of SPUR.

SUBBASIN REPORT FOR CHANNEL 2

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
FIELDS:													
RAINFALL	0.717	0.741	1.454	0.484	0.000	0.552	2.833	1.646	2.477	0.735	0.438	0.421	12.498
INFILTR	0.698	0.723	1.392	0.484	0.000	0.552	2.786	1.580	1.710	0.733	0.433	0.421	11.512
RUNOFF	0.018	0.018	0.062	0.000	0.000	0.000	0.048	0.066	0.767	0.002	0.006	0.000	0.985
SOIL:													
RTN FLOW	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
SOIL EVAP	1.048	0.551	0.388	0.745	0.000	0.348	1.772	1.040	1.150	0.747	0.416	0.415	8.621
PLANT EVAP	0.022	0.613	1.125	0.413	0.000	0.162	1.040	0.185	0.461	0.285	0.053	0.008	4.367
DEEP PERC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
STORAGE	1.236	0.794	0.674	0.001	0.000	0.042	0.015	0.370	0.469	0.170	0.134	0.132	
CHANNEL:													
LOSSES	0.004	0.004	0.009	0.000	0.000	0.000	0.008	0.008	0.010	0.002	0.004	0.000	0.050
RUNOFF	0.014	0.014	0.052	0.000	0.000	0.000	0.039	0.057	0.756	0.000	0.002	0.000	0.936
PEAK	10.8	10.6	35.5	0.0	0.0	0.0	27.7	38.2	572.7	0.0	1.3	0.0	572.7
BASIN WE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
LIVE VEG	38.34	217.05	289.25	352.46	320.89	269.02	258.44	85.09	120.79	43.53	10.56	2.15	
DEAD VEG	695.97	564.08	438.54	385.20	356.07	336.40	349.32	457.56	552.89	611.07	554.25	488.39	
SEDIMENT:													
FIELD SED	0.83	0.83	3.08	0.00	0.00	0.00	2.33	3.33	54.83	0.06	0.22	0.00	65.51
SILT-CLAY	0.28	0.28	1.48	0.00	0.00	0.00	1.04	1.65	40.84	0.00	0.01	0.00	45.58
BEDLOAD	1.16	1.14	5.33	0.00	0.00	0.00	3.85	5.91	98.28	0.00	0.06	0.00	115.73

Figure 3.55
Example of monthly/annual output report from the basin-scale version of SPUR.

BASIN LIVESTOCK REPORT FOR 1970

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
STEER (KG)	0.00	0.00	0.00	0.00	262.45	266.33	0.00	0.00	0.00	0.00	0.00	0.00	16.328
GRAZE DAYS	0	0	0	0	21	9	0	0	0	0	0	0	

Figure 3.56
Example of livestock output report from the basin-scale version of SPUR.

*********** ECONOMICS REPORT FOR 1970***

STEER PURCHASE COST	ANNUAL VARIABLE COST	TOTAL ANNUAL COSTS	POUNDS OF BEEF SOLD	GROSS REVENUE	NET REVENUE	NET PRESENT VALUE
738.54	6.00	744.54	1174.29	786.78	42.24	41.82

******* NET PRESENT VALUE 41.82

Figure 3.57
Example of economics output from the basin-scale version of SPUR.

4. USER GUIDE FOR THE CLIMATE GENERATOR

J.W. Skiles, E.P. Springer, C.W. Richardson

INTRODUCTION

As mentioned in chapters 2 and 3, the SPUR model requires that five weather variables be input per day of simulation. These are precipitation, maximum temperature, minimum temperature, solar radiation, and wind run. The weather generation package CLIMGN (Richardson and Wright 1984) is included in this release of the SPUR model because it has the capability of generating each of these variables on the daily basis required by SPUR. The main program of the climate generator is called CLIMGN. Reading, and writing (if desired), is accomplished in the main program. Generation of precipitation, temperatures, and solar radiation is done in the subprogram called WGEN, which is called by CLIMGN. Wind run generation is done in the subprogram named WINDGN, which is called by WGEN. Both subprograms, WGEN and WINDGN, as well as the main program call a random-number-generation subprogram, RANDN.

CLIMGN Control Record

After the title card is read (record 1), CLIMGN reads one record which controls program execution. Essentially, the user has four options for climate input to SPUR. He or she may have available all five variables on a daily basis and so may use actual data for model simulations, and consequently will have no need to use CLIMGN. The other three options require the use of CLIMGN. Should the user wish to generate all five weather variables, the control variable KGEN, read by the program from the control card, should be set equal to 1. In some circumstances, the user has available daily preciptitation data but needs the other four variables to be generated to run SPUR. In this case, KGEN should be set equal to 2. The final option is wind generation only. In this case, the user must supply observed precipitation, maximum temperature, minimum temperature, and solar radiation, and KGEN must be set equal to 3.

Note that KGEN controls the generation of weather variables, so one execution of CLIMGN produces only those variables so specified. That is, KGEN remains the same during each execution of the climate generator and may not be changed during execution.

The second and third variables read on the control card are KTCF and KRCF. These two flags control the adjustment of the generated temperature and rainfall based on user-supplied actual mean monthly values. The unadjusted rainfall and maximum and minimum temperatures are generated according to the parameters extracted from the tables and isograms supplied in chapter 10. CLIMGN can adjust these generated values according to actual mean monthly precipitation and temperature records to better represent the site's true climate. If KTCF is set to 0, no temperature adjustment will occur. When mean monthly temperatures are available, KTCF can be set to 1 and CLIMGN expects to read 12 mean monthly temperatures from card 13. When KTCF is set to 2, CLIMGN expects to read mean monthly maximum and minimum temperatures supplied on cards 13 and 14, 12 values per card. The KRCF flag allows rainfall quantities to be adjusted according to mean monthly rainfall records. When KRCF is set to 0, no rainfall adjustment will occur. IF KRCF is set to 1, CLIMGN expects to read mean monthly rainfall values supplied on card 15.

The fourth flag read on the control card is ICONV. If it is set to 1, CLIMGN converts the generated precipitation from inches to centimeters and the generated temperatures from degrees fahrenheit to degrees centigrade. (Note the the appropriate switch (KONVRT) on the second record of the SPUR simulation control and hydrology input file must be set to 1 if the precipitation and temperatures read by SPUR have the units centimeters and centigrade.) The variable IDAY is the Julian day on which the user wants the weather generation routines to start, and is typically set to 1. The next variable (IFYR) is the year (such as 1972 and 1985) in which the user wants the program to start generating weather. This variable assures that the program will generate weather for February 29th in leap years. The next flag (IPRT) controls an optional print file. If the switch has been set to 1, all the variables read by CLIMGN will be printed in report form on logical unit device number (LUN) 60. The next variable on the control card is NYRS. This is the number of years of weather the user wants generated. The final variable on the control card is XLAT which is the latitude of the field upon which the SPUR simulations are to be run.

CLIMGN File Structure

The program CLIMGN uses five Logical Unit Numbers (LUN's). Upon execution of CLIMGN, the user is prompted for the parameter file containing the climate generation control switches described above. The user is prompted for the parameter filename by the following statement:

ENTER NAME OF CLIMGN PARAMETER CONTROL FILE

The parameter file is then assigned LUN 55. Dependent upon the KGEN variable, the climatic record file is written, one record per day in the order listed above, on LUN 70, and is stored under the filename CLIMGN.070. If IPRT on the control card has been set to 1, the input variables will be written to LUN 60 and stored under the filename CLIMGN.060.

Climate generation codes (KGEN) 2 and 3 require an additional input file. To allow the use of non-CLIMGN standard data sets for these climatic generation options, CLIMGN requires the first record of these files to contain a FORTRAN format statement specifying the data format needed to read the record. The variables will be read in the order specified on the prompt for the filename. If KGEN is set equal to 2, the user must omit records 4 through 7, inclusive, from the

parameter file and the daily precipitation file will be opened on LUN 56. The user will be prompted for the file containing daily precipitation (one record per day) with the following statement:

ENTER NAME OF FILE THAT CONTAINS RAINFALL PER DAY

If KGEN is set equal to 3, the user must omit records 4 through 15, inclusive, from the parameter file, and the daily climatic file will be opened on LUN 50. The user will be prompted for the file containing precipitation, maximum and minimum temperatures, and solar radiation, one record per day, with the following statement:

ENTER NAME OF FILE THAT CONTAINS RAIN, TMAX, TMIN, & RAD

The CLIMGN Weather Generator Input

The variables read by CLIMGN from records 4 through 15 are fully described in chapter 2 of Part I. The user should understand how these variables are used in CLIMGN and how the values for the variables are derived before using the weather generator.

The four random-number-generator seeds, read from record 3, may be varied to alter the pattern of wet and dry years and the pattern of precipitation within a year in the generated data. Suppose that one sequence of seed numbers causes CLIMGN to produce 3 dry years and one wet year in a generated 4-year weather record. Further, suppose the user wants, for example, alternating wet and dry years or perhaps more precipitation during the wettest months and less in the dryer months. Rather than adjust the alpha and beta parameters (presumably derived from actual weather data) for these months, he or she may change the values of the random-number seeds, and again generate a weather record. The changes in the random-number seeds will alter the pattern of precipitation and temperatures generated by the program.

The user-supplied input for the weather generator, by variable name and format, is presented in table 4.1.

Program GENPAR

The Program GENPAR is also included with this release of SPUR. This program can be used to obtain most of the necessary parameters for CLIMGN as described in Richardson and Wright (1984). The program is designed to generate weather parameters for locations outside the 48 conterminous States or to develop parameters using actual data for specific locations. The major requirement for using GENPAR is that a weather record for a particular site be available. This record may have daily precipitation amounts or it may include daily maximum and minimum temperatures, daily solar radiation, as well as the daily precipitation measurements. The number of years of weather data required to develop parameters representative of a particular location vary with the climate. Generally, at least 20 years of precipitation data and 10 years of temperature and radiation data are required. Longer records of precipitation may be required for arid locations.

The main program of GENPAR reads the title, the control record, and the actual data. It also executes many of the write statements and all the calls to other subprograms. The Fourier coefficients for maximum and minimum temperature and solar radiation are calculated in the subprogram MSD. The precipitation probabilities and gamma-distribution parameters are calculated in the subprogram PPRAIN. No algorithms currently exist to calculate the parameters for the generation of wind run.

Execution of GENPAR

Following the title record (record 1), the control record (record 2) for program execution is read. A value of zero for the control variable KGEN will cause the program to calculate the parameters for generation of all the weather variables (with the exception of the wind generation parameters), Fourier coefficients for temperatures and radiation, and probabilities and distribution parameters for the precipitation. A KGEN value greater than zero will cause the program to calculate the parameters for precipitation generation only, that is, the probabilities and gamma-distribution parameters. This option is included because often a precipitation record may be at a site, but the other weather variables, temperatures and solar radiation, are missing. The remaining values on the control record are NYRS, the number of years of the weather record, and DLAT, the latitude of the measurement site, expressed in degrees. The arrays in the computer code are dimensioned to accommodate 30 years of actual record.

Record 3 is the FORTRAN format statement describing the weather data record. This record allows program flexibility so that weather data files can be read with different record formats. After the title and control records, the weather data records (record 4) are required. A data record is required for each observation (365 per year, 366 for a leap year). All units are English: temperature is in degrees Farenheit, precipitation is in inches, and solar radiation is in langleys.

Upon the beginning of execution, GENPAR will ask the user to specify the data file which holds the real weather data by writing the message on LUN 6:

ENTER NAME OF DATA FILE

The user responds by typing the name of the data file on LUN 5. The program opens the specified data file, on LUN 20 for use during execution. It also opens a file called GENPAR.PRM on device 60, which, at the end of execution, contains the generated parameters in report form.

Whole years of actual data must be supplied by the user. No year may be used wherein data are missing. The record for February 29 in leap years may be included. It is not used in the calculation of the weather generation parameters and is

Table 4.1
User-supplied input for Program CLIMGN (maximum air temperature is represented as TMAX, minimum air temperature as TMIN, and the coefficient of variation as CV)

Record number	Format	Variable name and description
RECORD 1	(80A1)	TITLE- maximum of 80 characters.
RECORD 2	(8I5,F10.2)	
	I5	KGEN- generation option code.
	I5	KTCF- temperature adjustment code.
	I5	KRCF- precipitation adjustment code.
	I5	ICONV- converts generated °F to °C and precipitation inches to centimeters.
	I5	IDAY- starting Julian day for generation.
	I5	IFYR- first year of generated weather.
	I5	IPRT- print parameters used to generate weather on logical unit 60 when IPRT=1.
	I5	NYRS- number of years of data to be generated.
	F10.2	XLAT- station latitude (degrees).
RECORD 3	(4I10)	K(1) through K(4)- random-number seeds (odd positive integers).
******************** If KGEN = 2, OMIT RECORDS 4, 5, 6 and 7 ******************		
************** If KGEN = 3, OMIT RECORDS 4 THROUGH 12, INCLUSIVE **************		
RECORD 4	(12F6.0)	PWW- the probability of a wet day preceded by a wet day for each month.
RECORD 5	(12F6.0)	PWD- the probability of a wet day preceded by a dry day for each month.
RECORD 6	(12F6.0)	ALPHA- gamma-distribution parameter for each month.
RECORD 7	(12F6.0)	BETA- gamma-distribution parameter for each month.
RECORD 8	(9F8.0)	
	F8.0	TXMD- mean of TMAX on dry days.
	F8.0	ATX- amplitude of TMAX on wet or dry days.
	F8.0	CVTX- mean of CV of TMAX on wet or dry days.
	F8.0	ACVTX- amplitude of CV of TMAX on wet or dry days.

Table 4.1--Continued
User-supplied input for Program CLIMGN (maximum air temperature is represented as TMAX, minimum air temperature as TMIN, and the coefficient of variation as CV)

Record number	Format	Variable name and description
RECORD 9	(9F8.0)	TXMW- mean of TMAX on wet days.
RECORD 10	(9F8.0)	
	F8.0	TN- mean of TMIN on wet or dry days.
	F8.0	ATN- amplitude of TMIN on wet or dry days.
	F8.0	CVTN- mean of CV of TMIN on wet or dry days.
	F8.0	ACVTN- amplitude of CV of TMIN on wet or dry days.
RECORD 11	(9F8.0)	
	F8.0	RMD- mean of solar radiation on dry days.
	F8.0	AR- amplitude of solar radiation on wet or dry days.
RECORD 12	(9F8.0)	
	F8.0	RMW- mean of solar radiation on wet days.
******************* If KTCF = 0, OMIT RECORDS 13 and 14 **********************		
RECORD 13	(12F6.0)	TM- mean monthly temperature or TTMAX- mean monthly maximum temperature.
********************** If KTCF = 1, OMIT RECORD 14 ****************************		
RECORD 14	(12F6.0)	TTMIN- mean monthly minimum temperature.
********************** If KRCF = 0, OMIT RECORD 15 ****************************		
RECORD 15	(12F6.0)	RM- mean monthly rainfall.
RECORD 16	(9F8.0)	
	F8.0	AVEL- mean wind speed for the year.
	F8.0	ASD- standard deviation of the wind speed for the year.
RECORD 17	(12F6.0)	VEL- average wind speed (mi/h) for months 1 through 12.

skipped by the program if it is included. If an incomplete weather year is included in the actual data file, the program will generate the message on LUN 60:

ABNORMAL TERMINATION DUE TO EOF BEING ENCOUNTERED

where EOF means "End Of File." If this occurs, the user should make sure the total number of records in the data file is a multiple of 365.

If the weather data supplied by the user does not contain enough records for the program to calculate a parameter, the message:

NOT ENOUGH DATA TO DEFINE PARAMETERS

is written to LUN 60. A longer weather data sequence is required for GENPAR to be of use. The user is directed to chapter 10 for a discussion of the variables that are calculated by GENPAR and that are used by CLIMGN.

The output of GENPAR is self-explanatory as it is the input for CLIMGN discussed previously. The format to be used in constructing data files for Program GENPAR are shown in table 4.2.

LITERATURE CITED

Richardson, C.W. and D.A. Wright. 1984. WGEN: A model for generating daily weather variables. U.S. Department of Agriculture, Agricultural Research Service, ARS-8, 83 p.

Table 4.2
Input for Program GENPAR

Record number	Format	Variable name and description
RECORD 1	(20A4)	TITLE- maximum of 80 characters.
RECORD 2	(2I5,F10.0)	
	I5	KGEN- parameter to control calculations.
	I5	NYRS- number of years of data.
	F10.0	DLAT- latitude of weather station.
RECORD 3	(80A1)	FMT- FORTRAN format statement describing the weather data record format (variable order described below).
RECORD 4	(FMT)	
	I2	IMO- month.
	I2	IDA- day of month.
	I2	IYR- year.
	F10.0	V1- maximum temperature (°F).
	F10.0	V2- minimum temperature (°F).
	F10.0	V3- precipitation (inches).
	F10.0	V4- solar radiation (ly).
******* THE FOLLOWING RECORD 4 INCLUDED ONLY IF KGEN GREATER THAN ZERO *****		
RECORD 4	(FMT)	
	I2	IMO- month.
	I2	IDA- day of observation.
	I2	IYR- year.
	F10.0	V3- precipitation (inches).

5. PLANT-COMPONENT PARAMETER ESTIMATION

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INTRODUCTION

The purpose of this chapter is to help the user determine reasonable parameter values for simulating the reaction of plants to various biotic and abiotic variables used in SPUR. Variables interacting with the plant component include competing plant species, weather, and soil moisture tension. Ideally, information about the parameters will be available from field or laboratory studies, where few, if any, changes will be needed for simulation experiments. Frequently, however, parameter values will not be available for the species of interest or the conditions being simulated. The user must select realistic values that will produce the desired production curves and physiological responses of the plants being simulated. The following sections provide guidance for parameter estimation. We assume the user has read and understands the background information presented in the plant component description, chapter 6 in Part I.

Between one and nine sites may be included in a simulation. The user must supply the initial levels of the four species-specific state variables (the PHYTM matrix) for each site (table 5.1). These are standing green biomass, live root biomass, propagule biomass, and standing-dead biomass of each species. Additionally, four site-specific state variables, dead root biomass (DROOTS), litter biomass (ALIT), soil organic matter (AORG), and soil inorganic-nitrogen concentration (SNIO) must be supplied.

No more than seven plant species may be simulated over the entire field (see chapter 2). That is, the model does not allow seven plant species on one site and seven species on another. The user-supplied parameters (the P matrix) and critical values (the CRIT matrix) for each species are used across all sites (table 5.2). Further, six site- and species-independent parameters (the PNS vector) must be supplied to control the rates of decomposition and denitrification.

GENERAL PARAMETERIZATION OF THE PLANT MODEL

To parameterize the SPUR plant model, the user must perform several simulation experiments using the model and compare model output with the expected results. As the user becomes more experienced, the user will find that only a few of the parameters need to be adjusted. These parameters deal primarily with decomposition and the timing of plant production. The user should become familiar with the sensitivity of the parameters before beginning the parameterization procedure (MacNeil et al. 1985 and chapter 8, Part I).

The following steps serve as an outline for "tuning" the model:

1. Develop an initial set of state variables and parameters. A useful set is included for the user's perusal (table 5.3).

2. Run SPUR. Determine if soil organic matter is approximately constant. In a 10-year simulation, for example, soil organic matter should be approximately the same at the end of the simulation as it was at the beginning.

3. Adjust decomposition rates for soil organic matter.

4. If the species are not responding properly, whether in magnitude or timing, ascertain the problem and modify the parameter file. If modifications are necessary, go to step 2.

5. Study the dynamics of litter and dead roots. If large accumulations or losses in either occur, adjust the decomposition rates accordingly. Go to step 4.

6. If changes have been made in the plant parameter file, go to step 2.

7. Begin to fine-tune the model by looking at the various indicator variables. Adjust the parameters so that the dynamics, both in magnitude and timing, agree with current knowledge about the system.

Table 5.1
Biomass state variables (g m^{-2}) for species S and site j of the rangeland plant model

Variable name	Definition	Variable name	Definition
$PHYTM_{1,S}$	Green shoots	$DROOTS_j$	Dead roots.
$PHYTM_{2,S}$	Live roots	$ALIT_j$	Litter.
$PHYTM_{3,S}$	Propagules	$AORG_j$	Soil organic matter.
$PHYTM_{4,S}$	Standing dead	$SNIO_j$	Soil inorganic nitrogen.

Table 5.2
Species-specific parameters ($P_{I,S}$) and critical values ($CRIT_{I,S}$) for species S, and nonspecies-nonsite-specific parameters (PNS_j) for site j of the SPUR plant component

	Definition	Unit
	P Matrix	
1	Theoretical maximum net photosynthetic rate	mg dm^{-2} h^{-1}
2	Light-use efficiency coefficient	m^2 W^{-1}
3	Maximum temperature for positive plant activity	°C
4	Optimum temperature for positive plant activity	°C
5	Minimum temperature for positive plant activity	°C
6	Water potential at which photosynthetic activity is one-half maximum	-bars
7	Drought tolerance coefficient	NOD[1]
8	Proportion of photosynthate translocated to roots after senescence begins	NOD
9	Maximum root-to-shoot ratio	NOD
10	Wind-tolerance coefficient (standing dead)	km^{-1}
11	Precipitation-tolerance coefficient (standing dead)	cm^{-1}
12	Proportion of phytomass susceptible to trampling	NOD
13	Susceptibility of standing dead to trampling	ha an^{-1}
14	Susceptibility of green shoots to trampling	ha an^{-1}
15	Proportion of green shoots susceptible to death	NOD
16	Phytomass to leaf area conversion factor	m^2g^{-1}
17	Proportion of photosynthate translocated to propagules after flower initiation	NOD
18	Proportion of root phytomass translocated to shoots	NOD
19	Germination proportion	NOD
20	Maintenance-respiration coefficient	mg g^{-1} day^{-1}
21	Proportion additional shoot death after senescence	NOD
22	NOT USED	
23	Seed-mortality proportion	NOD
24	Root-respiration proportion	NOD
25	Root-mortality proportion	NOD
26	Minimum percentage nitrogen for photosynthesis	NOD
27	Photosynthetic efficiency controlled by plant nitrogen	NOD
28	Maximum-nitrogen-uptake coefficient	g N g^{-1} day^{-1}
29	Nitrogen-use efficiency coefficient	m^2 g^{-1}
	CRIT Matrix	
1	Maximum leaf area index of green shoots	NOD
2	Temperature for frost kill	°C
3	Temperature for root to shoot translocation (TRS)	°C
4	Water potential for TRS	bars
5	Water potential for seed germination	bars
6	Julian day that seed production begins	NOD
7	Julian day that senescence begins	NOD
8	Julian day that senescence ends	NOD
	PNS Vector	
1	Proportion of dead roots susceptible to decomposition	NOD
2	Proportion of litter susceptible to decomposition	NOD
3	Proportion of organic matter susceptible to decomposition	NOD
4	Moisture tolerance of denitrification	-bars
5	Water potential at which decomposition activity is one-half maximum	-bars
6	Drought-tolerance coefficient for decomposition	NOD

[1] NOD means nondimensional.

Table 5.3
Species-specific parameters and initial conditions for species S of the SPUR plant component

Symbolic name	Species group				
	Warm-season grass	Cool-season grass	Warm-season forb	Cool-season forb	Shrub
$P_{1,S}$	75.0	25.0	20.0	12.0	15.0
2	0.4	2.0	0.15	1.3	1.3
3	45.0	37.0	45.0	35.0	40.0
4	27.0	20.0	27.0	20.0	21.0
5	5.0	3.0	5.0	3.0	3.0
6	25.0	10.0	15.0	7.0	8.5
7	9.96	6.29	7.04	4.75	6.4
8	.7	.7	.7	.7	.7
9	10.0	10.0	4.0	4.0	5.0
10	-.0001	-.0002	-.0004	-.0005	-.00002
11	-.25	-.4	-.6	-.65	-.00025
12	.05	.05	.06	.06	.0007
13	-.009	-.01	-.01	-.01	-.0009
14	-.005	-.006	-.006	-.006	.0
15	.004	.004	.004	.005	.0005
16	.015	.02	.03	.03	.03
17	.01	.02	.05	.05	.04
18	.005	.005	.005	.005	.005
19	.005	.01	.005	.005	.01
20	22.0	72.0	30.0	15.0	19.0
21	.06	.06	.05	.05	.05
22	.0	.0	.0	.0	.0
23	.01	.01	.01	.01	.01
24	.0025	.0025	.001	.0005	.0015
25	.005	.004	.002	.001	.0005
26	.008	.009	.010	.011	.01
27	-130.0	-115.0	-120.0	-110.0	-130.0
28	.003	.003	.002	.002	.001
29	.42	.42	.21	.21	.3
$CRIT_{1,S}$	3.0	3.0	3.0	3.0	3.0
2	-2.0	-6.0	-1.0	-3.0	-4.0
3	12.5	8.5	13.0	9.0	8.5
4	-12.0	-10.0	-12.0	-8.0	-8.0
5	-5.0	-3.0	-5.0	-3.0	-1.0
6	180.0	150.0	200.0	150.0	160.0
7	190.0	165.0	200.0	150.0	200.0
8	220.0	195.0	220.0	180.0	220.0
$PHYTM_{1,S}$	.0	.0	.0	.0	.0
2	256.4	62.7	35.0	32.4	45.0
3	.0	.0	.0	.0	.0
4	54.0	11.0	3.0	6.0	30.0

8. If changes have been made in the plant parameter file, go to 2.

9. After cycling through this procedure several times, and if adequate care was used, a data file will have been developed that will aid in making accurate simulations of the desired ecological system.

As the user parameterizes the model, attention should be paid to the similarities of the parameters. Do not make big changes, rather, use small well-planned changes in an attempt to converge upon a proper parameter file.

STATE VARIABLE VALUES

The initial values for the phytomass state variables and soil inorganic nitrogen will probably be obtained from existing data for the sites to be simulated. Data for live and dead shoot biomass should be available for each site. Soil inorganic nitrogen is very low in rangeland soils and during the active growing

season it may be trivial. The combined nitrogen input from fixation and rain is thought to be sufficient to maintain range productivity (Steyn and Delwiche 1970).

Litter biomass should also be available for each site. On ungrazed mixed grass prairie for the years 1968 through 1972, Coupland (1973) indicated that litter accumulation rose no higher than about 400 g m^{-2} and fell no lower than about 100 g m^{-2}. For a community of widely spaced perennials made up of mostly shrubs, Holmgren and Brewster (1972) reported 240 g m^{-2} aboveground litter. Parameters for the SPUR plant component should be assigned to reflect these fluctuations.

Soil organic matter in the upper 15 cm of the soil profile can be about 2000 g m^{-2} in Colorado shortgrass prairie. Holmgren and Brewser (1972) reported 1,530 g m^{-2} of accumulated organic biomass for a cold-desert shrub community. At three locations on a shortgrass prairie, Schimel et al. (1985) reported organic matter in the soil as ridgetop 1,916 g m^{-2}, backslope 1,846 g m^{-2}, and footslope 2,739 g m^{-2}. From a review in 1976, Coleman found that most of the total soil organic matter came from root production. He also found that plant, animal and microbial residues, root exudates, and exfoliates are the major sources of carbon in the soil (Coleman 1976). Soil organic matter should remain approximately constant throughout a simulation experiment.

Data for live root biomass ($PHYTM_{2,S}$), where S identifies the species) is a bit more difficult to obtain. Table 5.4 is provided to give some aid in determining the root biomass of several grassland types. Coupland (1974) reported the below-ground plant biomass on an ungrazed mixed grass prairie to a depth of 150 cm averaged 2,701 g m^{-2}. In the 0 to 30 cm layer, he reported 1,707 g m^{-2}. He did not distinguish between live and dead components of the biomass. Perhaps the best way to determine peak live root biomass, in the absence of real data, is to multiply the peak standing crop for a species by its maximum root:shoot ratio ($P_{9,S}$). If data are not available for dead roots, assume that the total root biomass is 70 percent dead and 30 percent live. Then, the initial dead root biomass is defined as:

$$DROOTS_j = \frac{0.7}{0.3} \sum_{S=1}^{nspec} PHYTM_{2,S} \qquad (1)$$

(This is equation (100) from chapter 6 in Part I.)

PARAMETER VALUES

The values given to the plant-component parameters determine the magnitude of response curves, the physiological dynamics of carbon and nitrogen metabolism, and transfer rates between compartments of the plant component. The necessary

Table 5.4
Peak aboveground and belowground phytomass (g m^{-2}) estimates for 5 arctic and 4 grassy ecosystems

Ecosystem type	aboveground		belowground	
	Live	Dead	Live	Dead
Polar desert	6	9	29	152
Arctic tundra	71	69	511	310
Typical arctic	188	366	1,370	4,856
Low arctic	218	521	2,307	7,788
Shrub-dwarf shrub	817	24	3,716	11,300
Steppes and prairies	238	260	1,425	1,525
Meadows I[1/]	425	182	1,600	1,650
Meadows II[2/]	275	165	1,188	538
Grassy swamps	575	275	1,675	4,800

[1/] Meadows I comprise steppe-like, mesophytic, mesohalophytic and hygrohalophytic meadows.

[2/] Meadows II comprise halophytic and hygrohalophytic meadows.

Note.--Arctic data are from Aleksandrova (1970) and grassland data are from Bazilevich and Titlyanova (1980).

precision of the parameters may be determined by examining the sensitivity analysis presented in chapter 9, Part I. In the discussions below, actual values or ranges for parameters and critical values are given when these values have been reported in the literature. Where no data were found, short discussions are presented with the intent that the user will formulate his or her own rules for finding the values of the variables. Along with these rules and the example data sets presented, the user should, with some experimentation, be able to derive a data set for the plant component which will produce acceptable model behavior for the site he wishes to simulate.

To help the user understand the operation of the model, an experiment was conducted to determine the effect of individual plant-component parameters on 26 SPUR indicator variables. Two simulation experiments were made for each of the 43 parameters listed in table 5.2; the first experiment increased the target parameter by an arbitrary amount, and the second experiment decreased the same parameter. A similarity index (the percentage of like effects on the indicator variables) was subsequently calculated between all combinations of parameters to determine the similarity of action on the indicator variables (table 5.5). The matrix of similarity indices showed that parameters clustered into eight primary groups (table 5.6). The groups included parameters that control (1) photosynthesis, (2) root biomass dynamics, (3) plant death, (4) phenology, (5) decomposition rate, (6) seed production and germination, (7) miscellaneous processes, and (8) nothing. The parameters will be discussed within the context of these groups, which will also help to develop an understanding of how the model operates. A sample parameter data file is shown in table 5.3.

PARAMETERS CONTROLLING PHOTOSYNTHESIS

The parameters controlling photosynthesis include numbers $P_{1,S}$, $P_{2,S}$, $P_{3,S}$, $P_{6,S}$, $P_{26,S}$, $P_{27,S}$, and $P_{28,S}$. Parameters $P_{4,S}$ and $P_{5,S}$ are discussed with $P_{3,S}$ so all three user-supplied points on the temperature response curve are considered together.

The parameters in this group tend to cause increases in plant-accumulated carbon and are reflected by increased biomass. As plant biomass increases, so does the transpiration rate causing decreases in plant-available water, deep percolation, and evaporation. (While this may seem counter-intuitive, it occurs because the plant-component calculations are done before the hydrology calculations are performed.) These parameters generally have no effect on peak percentage shoot nitrogen. Thus, on a biomass basis, plant nitrogen is diluted, causing a decrease in plant digestibility and an ultimate decrease in animal gain.

P1,S - Maximum Net Photosynthetic Rate

The theoretical maximum net photosynthetic rate (mg of CO_2 assimilated $dm^{-2}h^{-1}$) is one of the more important variables the user supplies. Typically, it is measured in gas exchange experiments in the field or laboratory using instruments and systems devised over the past two decades (see, for example, Moss 1963, Louwerse and Van Oorschot 1969, Sestak et al. 1971, and Dye and Hanson 1978). To maintain the separation between the C_3 Calvin-type photosynthesis (cool-season plants) and the C_4 dicarboxylic acid photosynthesis (warm-season plants) in the simulated plants, the C_4 parameter value will generally be higher than the value for the C_3 plant. Where only one type of pathway is used in a simulation with several plant species, the values can be very close to each other; the ecological separation between plant species in this instance is obtained from differences in the other parameters.

Some representative maximum photosynthesis rates for selected C_3 and C_4 plants are shown in table 5.7. Mooney (1972) gives the following ranges for plants under optimal temperature and water conditions, normal CO_2 concentrations, and light saturation: cultivated C_3 plants, 20-35; C_4 plants, 30-70; herbs from sunny habitats, 4-16; herbs from shaded habitats, 4-12; deciduous broad-leaf plants, 10-25; and for Ericaceae and semiarid sclerophyllous shrubs, 4-12 (also see Moore 1977). Photosynthetic rates are generally lower in evergreen than in deciduous species from the same environment (Mooney 1972, Orians and Solbrig 1977). Also, plants on infertile sites have lower photosynthesis and growth rates (Chapin 1980) because stressed leaves contain less photosynthetic machinery and have higher CO_2 resistances (Orians and Solbrig 1977) than hardy leaves.

$P_{2,S}$ - Light-Use Efficiency Coefficient

The light-use efficiency coefficient (m^2 W^{-1}) is important to SPUR, but its control on the indicator variables is exactly the same as $P_{1,S}$. This parameter controls the rate at which the plant reaches the maximum net photosynthesis rate. However, in most instances, the plant will be light saturated for a major portion of the day, and therefore, be operating at its maximum photosynthetic rate. So, this parameter should be considered of lesser importance than $P_{1,S}$ unless plants are directly competing for light. Once a value is determined for $P_{2,S}$, it should remain constant and the user should adjust the model output using $P_{1,S}$.

Evidence exists showing that $P_{2,S}$ is not constant. Hanson and Dye (1980) showed the absorption coefficient of Prosopis glandulosa var. gladulosa varied throughout the growing season in response to tissue age, water stress, and temperature. Hanson (1982) reported that light-use efficiency for this species also varied in reponse to ecotypic variation.

The absorption coefficient and the light-use efficiency coefficient are similar in that they describe how well plants absorb light. The ultimate effect is that some plants become light saturated at very low levels of light, while others are not saturated even at full sunlight. In general, C_3 plants and shade-tolerant plants

Table 5.5
Effect of perturbing parameter I for species S on various indicator variables of the SPUR plant model. Numbers at the top are the same as those used for the parameters listed in table 5.2

Indicator variable	$P_{1,S}$																												
	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
Deep percolation	I	I	I	P	P	N	N	N	P	I	N	N	N	N	N	I	N	I	N	N	N	N	N	P	P	P	I	I	N
Evaporation	I	I	I	P	P	I	N	N	P	I	N	N	N	P	P	I	N	I	N	N	P	N	N	P	P	P	I	I	P
Plant-avail. water	I	I	I	P	P	I	P	N	P	U	P	N	N	P	P	I	N	I	N	P	P	N	N	P	P	P	I	I	P
Transpiration	P	P	P	I	I	P	I	N	I	U	I	N	N	I	I	P	N	U	N	I	I	N	N	I	I	I	P	P	I
Plant biomass	I	I	I	U	P	I	P	N	P	U	I	I	I	I	I	U	I	I	N	I	N	N	N	I	I	I	P	U	U
Peak standing crop	P	P	P	U	P	P	P	N	I	U	I	N	N	I	I	U	N	I	N	I	N	N	N	I	I	I	P	P	I
Date PSC[1] 1/	I	I	I	U	P	P	N	N	P	N	N	N	N	P	I	I	N	I	N	I	N	N	N	P	P	P	I	I	P
Root respiration	P	P	P	U	I	P	N	N	P	P	I	N	N	I	I	I	N	I	N	I	N	N	N	P	I	I	P	P	I
Shoot respiration	P	P	P	U	U	P	I	N	P	I	I	N	N	I	I	I	N	I	N	P	N	N	N	P	I	I	P	P	I
Shoot-root trans.[2]	P	P	P	U	U	P	I	N	P	I	I	N	N	I	I	I	N	U	N	I	N	N	N	P	U	I	P	P	I
Root-Shoot trans.	U	U	P	I	I	P	I	N	P	I	I	N	N	I	I	I	N	P	N	N	N	N	N	I	I	I	U	P	I
Root mortality	P	P	I	P	P	P	I	N	P	U	I	N	N	I	I	U	N	I	N	I	I	N	N	I	P	I	P	P	I
Total C. assimil.	P	P	P	U	U	P	I	N	P	I	I	N	U	I	I	U	N	I	N	I	N	N	N	P	I	I	P	P	I
Total shoot death	P	P	P	U	U	P	I	I	I	U	I	N	N	I	P	P	N	U	N	I	P	N	N	I	I	I	P	P	I
Total EMP[3]	I	I	I	U	P	P	N	N	P	N	N	N	N	P	P	I	N	I	N	P	N	N	N	P	P	P	I	I	P
Total photosyn.	P	P	P	U	U	P	I	N	P	I	I	N	N	I	I	I	N	I	N	P	N	N	N	P	I	I	P	P	I
Total EMD[4]	I	I	I	P	P	I	P	N	P	I	N	N	N	P	P	I	N	I	N	N	P	N	N	P	P	P	I	I	P
Peak % shoot N	N	N	P	I	I	N	N	N	N	N	N	N	N	N	N	I	N	I	N	N	N	N	N	P	I	N	N	N	N
Date peak % SN[5]	N	N	I	P	P	N	N	N	N	N	N	N	N	N	N	I	N	I	N	N	N	N	N	P	I	N	N	N	N
Total ETNU[6]	N	N	P	I	I	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Total EMNU[7]	I	I	I	P	P	I	N	N	P	I	N	N	N	P	P	I	N	I	N	N	P	N	N	P	P	P	I	I	P
Total EMDN[8]	I	I	I	P	P	I	N	N	P	I	N	N	N	P	P	I	N	I	N	N	P	N	N	P	P	P	I	I	N
Total mineral N	I	I	I	P	P	I	P	N	P	U	P	N	N	P	P	I	N	I	N	P	P	N	N	P	P	P	I	I	P
Animal gain	I	I	I	U	P	I	P	N	P	U	P	N	N	I	P	I	I	I	N	P	U	N	N	P	I	P	I	P	I
Harvested live	I	I	I	U	U	I	P	P	P	U	P	P	P	I	U	I	I	I	N	P	I	N	N	P	I	P	I	P	I
Harvested dead	I	I	I	U	P	I	P	I	P	U	I	P	U	I	U	I	I	I	N	P	U	N	N	P	I	P	I	I	I

	$CRIT_{1,S}$								PNS_j					
	1	2	3	4	5	6	7	8	1	2	3	4	5	6
Deep percolation	N	I	P	N	N	N	N	N	P	P	I	N	N	N
Evaporation	N	P	P	N	N	N	I	I	P	P	I	N	I	I
Plant-avail. water	I	U	P	N	N	N	I	I	P	P	I	I	I	I
Transpiration	P	I	I	N	N	N	P	P	I	I	P	N	P	P
Plant biomass	P	I	U	N	N	N	N	N	I	I	P	P	P	P
Peak standing crop	P	I	U	N	N	N	N	N	I	I	P	P	P	P
Date PSC	N	P	U	N	N	N	N	N	P	P	I	N	I	I
Root respiration	P	I	U	N	N	N	N	N	I	I	P	N	P	P
Shoot respiration	P	I	P	N	N	N	P	P	I	I	P	P	P	P
Shoot-root trans.	P	I	P	N	N	N	P	P	I	I	P	P	P	P
Root-shoot trans.	P	I	P	N	N	N	P	P	I	I	P	N	P	P
Root mortality	P	I	I	N	N	N	P	P	I	I	P	P	P	P
Total C. assimil	P	I	U	N	N	N	P	P	I	I	P	P	P	P
Total shoot death	P	P	I	N	N	N	P	P	I	I	P	P	P	P
Total EMP	N	P	P	N	N	N	N	N	P	P	I	N	I	I
Total photosyn.	P	I	P	N	N	N	P	P	I	I	P	P	P	P
Total EMD	N	P	P	N	N	N	I	I	P	P	I	N	P	P
Peak % shoot N	N	N	U	N	N	N	N	N	N	N	N	N	N	N
Date peak % SN	N	N	U	N	N	N	N	N	N	N	N	N	N	N
Total ETNU	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Total EMNU	N	P	P	N	N	N	I	I	P	P	I	N	I	N
Total EMDN	N	P	P	N	N	N	I	I	P	P	I	I	N	N

Table 5.5--Continued
Effect of perturbing parameter I for species S on various indicator variables of the SPUR plant model. Numbers at the top are the same as those used for the parameters listed in table 5.2

Indicator variable	$CRIT_{1,S}$	PNS_j
Total mineral N	N P P N N N I I	I I P P P I
Animal Gain	I U U N N N P P	I I P P P P
Harvested live	I I U N N P P P	I I P P P P
Harvested dead	P P U N N I P P	I I P P P P

_/1--PSC = Peak standing crop; 2--Trans. = Translocation; 3--EMP = Effect of moisture on photosynthesis; 4--EMD = Effect of moisture on decomposition; 5--SN = Shoot nitrogen; 6--ETNU = Effect of temperature on nitrogen uptake; 7--EMNU = Effect of moisture on nutrient uptake; 8--EMDN = Effect of moisture on denitrification.

Note.--P means the parameter is proportionally related to the indicator variable; I means an inverse relationship exists between the parameter and the indicator variable; N means the parameter perturbation did not affect the indicator variable; and U means the effect of parameter perturbation on the indicator variable is unpredictable.

Table 5.6
Parameter clusters for the SPUR plant model for species S

Process controlled	Parameter
Photosythesis	$P_{1,S}$, $P_{2,S}$, $P_{3,S}$, $P_{4,S}$, $P_{5,S}$, $P_{6,S}$, $P_{26,S}$, $P_{27,S}$, $P_{28,S}$
Root biomass dynamics	$P_{9,S}$, $P_{24,S}$
Plant death	$P_{14,S}$, $P_{15,S}$, $P_{25,S}$, $P_{29,S}$, $CRIT_{2,S}$,
Plant phenology	$CRIT_{7,S}$, $CRIT_{8,S}$
Decomposition and denitrification	PNS_1, PNS_2, PNS_3, PNS_4, PNS_5, PNS_6
Seed production and germination	$P_{17,S}$, $P_{19,S}$, $P_{23,S}$, $CRIT_{5,S}$, $CRIT_{6,S}$
Miscellaneous processes	$P_{7,S}$, $P_{10,S}$, $P_{11,S}$, $P_{16,S}$, $P_{18,S}$, $P_{20,S}$, $P_{21,S}$, $CRIT_{1,S}$, $CRIT_{3,S}$, $CRIT_{4,S}$
Preset or unused	$P_{8,S}$, $P_{12,S}$, $P_{13,S}$, $P_{22,S}$

Table 5.7
Maximum photosynthetic rates (mg CO_2 dm^{-2} hr^{-1}) and putative photosynthetic pathways for selected plant species

Scientific name	Rate	Pathway	Reference
Acacia craspedocarpa	2	C_3	Grieve and Hellmuth 1970
Acacia craspedocarpa	2.4	C_3	Hellmuth 1971
Acacia craspedocarpa	1.4	C_3	Hellmuth 1971
Agropyron smithii	14.4	C_3	Moore 1977
Alopecurus alpinus	16	C_3	Tieszen 1973
Amaranthus edulis	58	C_4	El-Sharkawy et al. 1967
Andropogon gerardi	47	C_4	Tieszen 1970
Andropogon scoparius	25	C_4	Tieszen 1970
Artemisia tridentata	2-6	C_3	DePuit & Caldwell 1973
Atriplex hasta	42	C_3	Slayter 1970
Atriplex spongiosa	77	C_4	Slayter 1970
Bromus inermis	19	C_3	Tieszen 1970
Bouteloua curtipendula	36	C_4	Tieszen 1970
Bouteloua gracilis	44	C_4	Dye et al. 1972
Calamagrostis holmii	13	C_3	Tieszen 1973
Calamovilfa longifolia	24	C_3	Tieszen 1970
Cenchrus ciliaris	66	C_4	Ludlow & Wilson 1971
Chloris gayana	53	C_4	Ludlow & Wilson 1971
Dactylis glomerata	9-16	C_3	Charles-Edwards et al. 1971
Dupontia fischeri	17	C_3	Tieszen 1973
Elymus arenarius	31	C_3	Tieszen 1973
Elymus canadensis	28	C_3	Tieszen 1973
Encelia farinosa	48	C_4	Cunningham & Strain 1969
Eucalyptus marginata	3-4	C_3	Grieve & Hellmuth 1970
Festuca arundinacea	14-17	C_3	Charles-Edwards et al. 1971
Festuca arundinacea	12-20	C_3	Woledge 1971
Helianthus annus	12-14	C_3	Neales et al. 1968
Helianthus annus	28	C_3	Bull 1969
LoLium perenne	12-15	C_3	Charles-Edwards et al. 1971
Panicum maximum	55-70	C_4	Ludlow & Wilson 1971
Panicum vigatum	40	C_4	Tieszen 1970
Pennisetum purpureum	73	C_4	Ludlow & Wilson 1971
Prosopis glandulosa	11-31	C_3	Hanson & Dye 1980
Prosopis glandulosa	25-30	C_3	Hanson 1982
Poa arctica	11	C_3	Tieszen 1973
Poa sandbergii	2-4	C_3	Hironaka & Tisdale 1973
Rhagodia baccata	3-4	C_3	Grieve & Hellmuth 1970
Rhus integrefolia	10-14	C_3	Moore 1977
Rhus laurina	18-20	C_3	Moore 1977
Schizachyrium gerardi	47	C_4	Tieszen 1970
Sitanion hystrix	8-14	C_3	Hironaka & Tisdale 1973
Setaria spacelata	51	C_4	Ludlow & Wilson 1971

Table 5.7--Continued
Maximum photosynthetic rates (mg CO_2 dm^{-2} hr^{-1}) and putative photosynthetic pathways for selected plant species

Scientific name	Rate	Pathway	Reference
Spartina pectinate	30	C_4	Tieszen 1970
Stipa comata	17	C_3	Tieszen 1970
Tidestromia oblongifolia	58	C_4	Björkman et al. 1972
Typha latifolia	44-69	C_3	McNaughton & Fullem 1970

become light saturated at lower light levels than C_4 plants and plants that require high light levels. The light-use efficiency coefficient for C_3 plants should, therefore, be greater than 1.0 and perhaps as high as 5.0 or more. For C_4 plants, $P_{2,S}$ should be less than 1.0. These are, however, only general rules of thumb and the parameters should be derived from data fit to the light-use response curve presented in Part I, figure 6.3). (Also see Hanson 1982.)

$P_{3,S}$, $P_{4,S}$, $P_{5,S}$ - Maximum, Optimum and Minimum Temperatures

Plant physiologists (for example, Salisbury and Ross 1969) have documented three characteristics of temperature as it relates to plant growth: Minimum air temperature below which no growth occurs; (2) maximum air temperature above which no growth occurs; and (3) an optimum air temperature where the growth rate of a plant species is optimum (maximum). Another way of describing this is that for every plant, an area of low-temperature inactivation exists, an area of optimum activity, and an area of high-temperature deactivation (Sharpe and DeMichele 1977). Though actual structural damage can occur when plant temperature is elevated to the area of high-temperature deactivation, this is not considered in the SPUR plant growth model.

The parameters (all in °C) used to describe the response of plant activity to temperature are maximum temperature, optimum temperature, and minimum temperature for positive physiological activity, $P_{3,S}$, $P_{4,S}$, and $P_{5,S}$, respectively. Physiological responses of plants are functions, in part, of temperature and moisture. The temperature may be that of the air or the soil, and the moisture may be that of the atmosphere, soil, or the plant tissue itself. So, depending on the process being simulated, the model uses the same temperature parameters but uses temperatures estimated from different points within the system. For this reason, the three parameters should be estimated together since each specifies a point on the species' temperature response curve.

For the shortgrass prairie C_4 plant Bouteloua gracilis, Connor et al. (1974) reported a value of 26.4 °C for the optimum temperature for photosynthesis in a functional model; physiological activity occurred in a range of plus or minus 15 °C around this optimum. Laboratory studies have shown optimal temperatures for this species of about 30 °C.

Under light-saturated conditions, Ehleringer and Björkman (1977) and Ehleringer (1978), in a simulation model, used temperature optima for photosynthesis of 25 °C and 35 °C for C_3 and C_4 species, respectively. Most C_3 plants have temperature optima within the range 15-25 °C (Larcher 1969). Warm-season plants have photosynthetic optima within the range 30-45 °C (Hesketh and Baker 1969) and the highest reported optimum was 48 °C (Björkman et al. 1972). The general relationship between C_3 and C_4 plants is that maximum, optimum, and minimum temperatures for C_4 species are higher than the respective temperatures for C_3 species (fig. 5.1). The general relationship between temperature and relative net photosynthesis is shown in figure 5.2.

Growth form and habitat should also be considered in separating plants having the same carbon fixation pathway. Thus, a shrub and a cool-season forb might perhaps have the same photosynthetic mechanism, but the shrub is generally taller than the forb and away from the warmer ground temperatures to which the forb is subjected. Physiological response temperatures should, therefore, be adjusted accordingly since the SPUR model does not account for plant height.

Parameter $P_{3,S}$ has more control over photosynthesis than the other two temperature parameters. The parameter has almost identical action as the parameters controlling plant photosynthesis, except that it affects those indicator variables describing nitrogen dynamics. So, if $P_{3,S}$ is increased, then peak percentage shoot nitrogen is increased.

Parameter $P_{5,S}$ has almost the opposite effect on the indicator variables as $P_{3,S}$. However, the effect of this parameter cannot always be predicted. The responses of the model to $P_{4,S}$ and $P_{5,S}$ show the large number of interactions

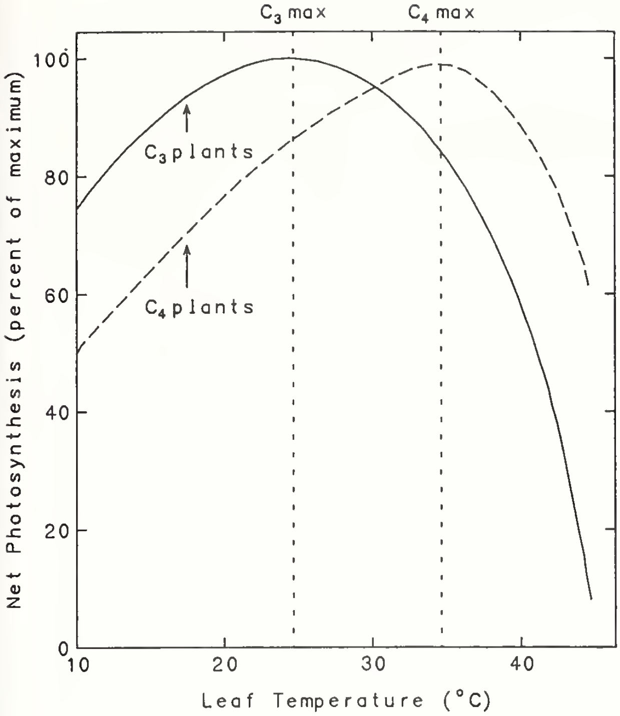

Figure 5.1
Net photosynthesis as a function of leaf temperature in typical C_3 and C_4 plants (Ehleringer and Björkman 1977).

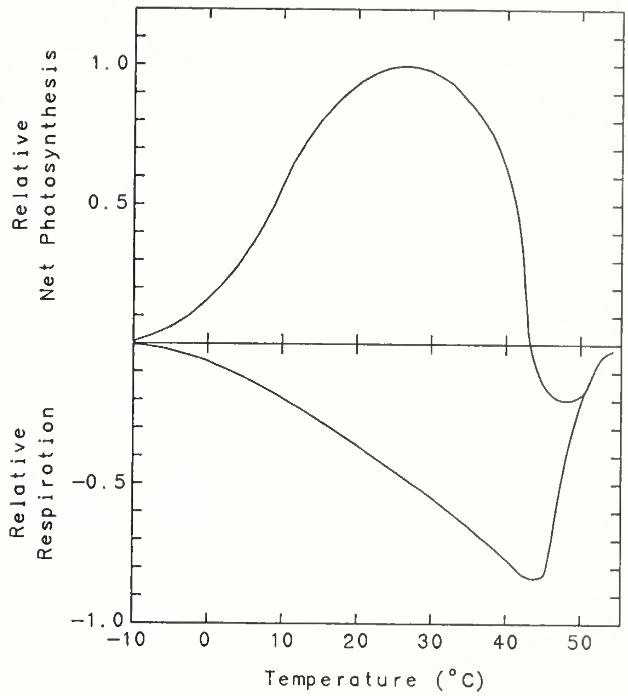

Figure 5.2
The general relationship between temperature and relative net photosynthesis and temperature and relative respiration (after Gates 1968).

occuring within SPUR. The model is largely nonlinear, thus the response surface is often rough, and depending upon the degree of change in the parameters, the exact response for some of the indicator variables cannot be predicted. Therefore, our recommendation for parameters $P_{3,S}$, $P_{4,S}$, and $P_{5,S}$ is to set their values and maintain those values over all simulation experiments for a given rangeland system.

$P_{6,S}$ - Water Potential for One-half Maximum Photosynthesis

The parameter $P_{6,S}$ (-bars) is the soil-water potential at which photosynthetic activity is at one-half maximum. The parameter value is a positive real number since soil moisture potentials are reported as negative numbers. The literature does not directly discuss $P_{6,S}$, so it must be approximated from what is known about the species under consideration. The relationship between soil-water potential and net photosynthesis is shown in figure 5.3. After a number of simulation experiments, we found for C_4 plants that the parameter should be about 15.0 to 25.0; grasses should have the larger value and forbs, the smaller value. For C_3 plants, the values should range from about 5.0 to 12.0, again giving the grasses a higher value than the forbs. Shrubs have values between those of grasses and forbs.

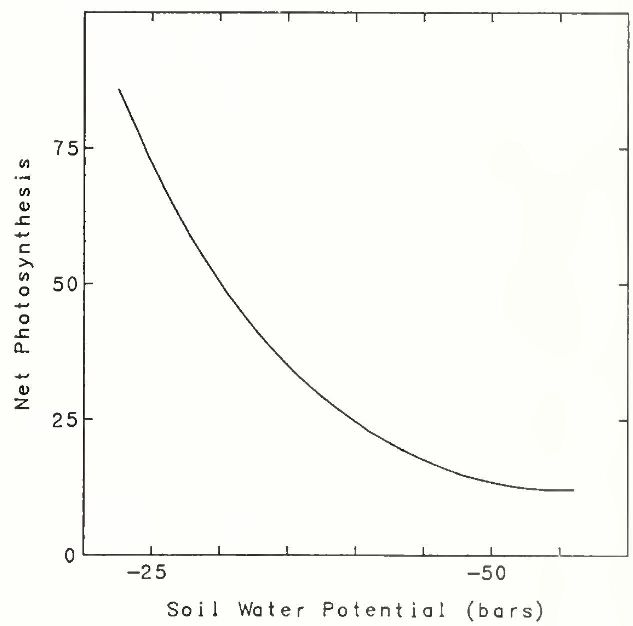

Figure 5.3
Net photosynthesis as a function of soil water potential (after Oechel et al. 1972).

$P_{26,S}$ - Minimum Percentage Nitrogen for Photosynthesis

This parameter controls the minimum percentage shoot nitrogen at which photosynthesis can occur and operates in opposition to the other parameters in this class. Thus, increases in $P_{26,S}$ cause increases in deep percolation, evaporation and plant-available water. This, in turn, decreases plant biomass; however, rather than decreasing harvested live and dead material, these materials actually increase (see table 5.5). The net result is an increase in animal gain. Murata (1969) has discussed the relationship between nitrogen and photosynthesis (see also Fried and Broeshart 1967, Rorison 1969, and Whitehead 1970). In cultivated rice leaves, maximum photosynthetic rate was reduced by about 50 percent when nitrogen content was reduced from 5 to 2 percent. We found in experiments with the SPUR model that photosynthesis should not stop in grassland species until shoot nitrogen is about 0.8 (0.008 in the input file) to 1.0 percent (0.01 in the input file).

$P_{27,S}$ - Nitrogen-Controlled Photosynthetic Efficiency

Photosythesis is controlled by the percentage of nitrogen in the shoot. The nondimensional parameter $P_{27,S}$ controls plant nitrogen-use efficiency. The value of $P_{27,S}$ is negative.

Photosynthetic rate has been reported to be proportional to leaf nitrogen concentration because the bulk of leaf nitrogen is a component of photosynthetic enzymes and is, therefore, directly involved in the photosynthetic process (Chapin 1980). Increasing the magnitude of $P_{27,S}$ allows the simulated plant to photosynthesize at high rates even when plant nitrogen is low. For this parameter, we found that values generally range between -110.0 and -130.0, and that warm-season plants have larger nitrogen efficiency coefficients than cool-season plants.

$P_{28,S}$ - Maximum Nitrogen-Uptake Rate

Maximum nitrogen-uptake rate (g N g^{-1} root C day^{-1}) is also important in controlling photosynthesis because this regulates the rate at which nitrogen eventually gets to the leaves. Schimel et al. (1985) report that below-ground material, including live and dead roots of all species, had N concentrations of 1.7 to 1.9 percent. Sheldrake and Narayanan (1979) showed that nitrogen uptake-rate varied throughout the growing season. However, we assume in SPUR that the maximum rate is constant, and that nitrogen uptake-rate is reduced during the growing season because of limiting inorganic nitrogen and water stress. Actual estimates of this parameter vary. McGill et al. (1981) used values ranging from 0.001 to 0.020 for fungi and grass roots, respectively, in a model of carbon and nitrogen dynamics of grassland soils. Reuss and Innis (1977), when simulating nitrogen flow within grasslands, estimated maximum nitrogen uptake to be 0.002. Extrapolated data from Bigeriego et al. (1979) show that nitrogen uptake of fertilized corn was approximately 0.076. In SPUR we found that values ranging from 0.001 to 0.010 produce nitrogen response curves which seem to fit the curves found in the literature. Grasses have the highest maximum nitrogen uptake rate, forbs the second highest, and shrubs the lowest rate.

PARAMETERS CONTROLLING ROOT BIOMASS DYNAMICS

Parameters $P_{9,S}$ and $P_{24,S}$ control root dynamics in the SPUR model. This class of parameters tends to act in opposition to the parameters controlling photosynthesis. Increases in $P_{9,S}$ and $P_{24,S}$ cause increases of deep percolation, evaporation, and plant available water which subsequently decrease transpiration. The result of increasing the root biomass control parameters is an increase in animal intake (both live and dead) leading to an increase in animal weight gain.

$P_{9,S}$ - Maximum Root-to-Shoot Ratio

The unitless parameter $P_{9,S}$ is the maximum live-root-to-shoot ratio (R/S). A root-to-shoot ratio of 8.0, for example, means that 8 grams of live roots are required to support one gram of green shoots. When the maximum R/S for a specific species is reached during a simulation, biomass translocation to or from the roots is triggered for that species. Increases in $P_{9,S}$ cause a decrease in peak standing crop, but an overall increase in total plant biomass.

Within the context of a plant community, no absolute trend between classes of plants and their root-to-shoot ratios exists (Mooney 1972, Struik and Bray 1970, Whittaker 1962). Rodin and Bazilevitch (1967) estimated that well over 50 percent of the plant biomass of arctic, desert, and grassland communities is in the roots. The R/S for perennials was lower in habitats where light is limiting (Kozlowski 1971, Lyr et al. 1969) than in habitats where water or minerals are limiting (Struik and Bray 1970, Biddiscombe et al. 1969). A higher R/S occurred in ecosystems where shoots were subject to fire or grazing (Whittaker and Woodwell 1968). Additionally, R/S of field species from infertile habitats were about 5 times higher than those measured in solution culture (Chapin 1974, Dennis and Johnson 1970). From data by Bazilevich and Titlyanova (1980), steppe and prairie plant communities averaged 6.0 R/S and ranged from 0.4 to 15.2. For more mesic conditions found in meadows, an average R/S of 3.7 and a range of 2.3 to about 4.0 existed. Aleksandrova (1970) presented an R/S of 4.8 for polar deserts, 7.2 for herb-dwarf shrub tundra, 7.3 for typical tundra, 10.6 for sedge-moss-dwarf shrub low-arctic ecosystems, and 4.5 for subarctic shrub dwarf-shrub ecosystems. On a mixed grass prairie, Coupland (1974) reported a mean R/S, for all months, of 5.7 with a maximum value in mid-May and a value minimum of 3.9 in early July.

These values are not for individual plant species but rather for whole plant communities and may be useful, after tuning, for single-species simulations. Our only rule of thumb for determining R/S for a particular species is that grasses have

a much higher root biomass than shrubs, causing a higher R/S in grasses than shrubs; shrubs have a slightly higher R/S than forbs. Actual field or laboratory data are, of course, preferable.

$P_{24,S}$ - Root-Respiration Proportion

The parameter $P_{24,S}$ is the nondimensional proportion of root biomass that can be respired on a given day. The effect of this parameter differs from $P_{9,S}$ because increases in $P_{24,S}$ cause decreases in plant biomass, total root to shoot translocation, and overall root mortality. The parameter affects root mortality because as root respiration increases, less root biomass remains to be killed through natural causes. Carbon lost through the process of respiration is lost to the organic carbon pool of the model; however, nitrogen is conserved. No estimates of the magnitude of this parameter exist. In general we allowed grasses to have the highest respiratory rate. Shrubs were set slightly lower than grasses, and forbs given the lowest susceptibility to respiratory loss.

PARAMETERS CONTROLLING PLANT DEATH

Plant mortality is controlled by parameters $P_{14,S}$, $P_{15,S}$, $P_{25,S}$, $P_{29,S}$, and $CRIT_{2,S}$. Dying shoots can be transferred either to the standing dead compartment or the litter compartment. Warembourg and Paul (1977) reported minimum death rates occurred in June and July. Root mortality is largely a function of water stress (Ares 1976). Rates were shown to be maximum when the soil water was low and during late summer months (probably because of an aging factor). Actual estimates of shoot mortality have been made by Kelly et al. (1969), Singh and Yadava (1974), and Sims and Singh (1978b). Singh and Coleman (1974) reported that the proportion of live roots remained fairly constant throughout the growing season. This indicated that about as many new roots were being produced as were dying throughout the growing season. In SPUR, parameters $P_{14,S}$, $P_{15,S}$, $P_{29,S}$, and $CRIT_{2,S}$ control shoot death and $P_{25,S}$ controls root death.

$P_{14,S}$ - Susceptibility of Green Shoots to Trampling

The parameter $P_{14,S}$ (ha an^{-1}) controls the susceptibility of green material to grazing pressure. Increases in the parameter cause peak standing crop to decrease, eventually decreasing available forage to grazing animals and decreasing animal gain. Thus, as hoof action increases with increased stocking rates, plants with high susceptibilities to grazing (those with high negative values for $P_{14,S}$) will be trampled and become litter and, therefore, be unavailable to grazing animals. Values for this parameter are not available for most species. In SPUR, we have been assigning similar values to grasses and forbs (-0.005) while we have set the parameter to 0.0 for shrubs. This means that cattle do not trample shrubs.

$P_{15,S}$ - Susceptibility of Green Shoots to Death

This parameter determines the maximum percentage of shoots that can die on a given day. In northern temperate grassland, this parameter should be set so that the entire year's production is turned over during the growing season. Singh et al. (1980) present a review of shoot turnover rates. In SPUR grasses were given the most rapid turnover rate, followed by forbs, and then shrubs. Values for $P_{15,S}$ of 1 percent or less seem reasonable.

$P_{25,S}$ - Root Mortality

Root mortality is controlled by $P_{25,S}$. As with the $P_{15,S}$, this parameter sets the maximum percentage of root biomass susceptible to mortality per day. Chapin (1980) from a review of the literature concluded there was a greater root longevity in infertile, nutrient-poor habitats. Live roots typically have an N content of 1.1 percent, whereas detrital and senescent roots have an N content of about 2.5 percent (Clark 1977). Values of 0.5 percent or less should be used. The same relationship between species groups should be used for $P_{25,S}$ as for $P_{15,S}$.

$P_{29,S}$ - Nitrogen Use Efficiency

The nitrogen-use efficiency coefficient (m^2 g^{-1}) is important in determining the actual nitrogen content of the plant and thus, the vigor of the plant. Grasses seem to have about twice the nitrogen-use efficiency of forbs (McGill et al. 1981). Shrubs and forbs have little difference. In a review, Brown (1978) postulated that C_4 plants have a greater nitrogen-use efficiency than do C_3 plants. He contends that this difference results from the relatively smaller investment of N in the photosynthetic carboxylation enzymes of C_4 plants as compared with C_3 plants. Small (1972) asserted that a useful measure of efficiency might be respiration, photosynthetic, or net assimilation rate per gram of nutrient. Since this parameter is not discussed in great detail in the literature, our suggestion is to begin with values such as 0.42, 0.21, and 0.30 for grasses, forbs, and shrubs, respectively.

$CRIT_{2,S}$ - Frost Kill Temperature

This parameter determines the temperature at which frost begins to kill plant tissue. We assumed that most plants of the grassland ecosystem can withstand temperatures slightly below freezing. Warm-season (C_4) plants are the most susceptible to cold, and frost damage can occur at temperatures slightly below 0 °C (-2 to -3 °C), whereas C_3 plants can withstand temperatures perhaps as low as -6 °C.

PARAMETERS CONTROLLING PLANT PHENOLOGY

Rather than explicitly simulate the phenological stages of a plant species, as was done for the ELM project (Innis 1978), and thereby increase the

number of user-supplied values required to use the model, the SPUR plant component allows the user to initiate phenological phenomena through the use of critical values. User knowledge of the actual system and the plant species being simulated is required to supply these values.

$CRIT_{7,S}$ - Julian Day that Senescence Begins

This is the Julian day that plant senescence begins. The date is probably on or around the day of peak standing crop. According to Williams (1948, 1955), up to 90 percent of the maximum leaf nitrogen is translocated out of senescing leaves before abscission. Half or more of the maximum nitrogen content of a deciduous leaf is translocated to other plant parts before abscission (Williams 1948, Chapin 1980). In SPUR we increase the translocation of photosynthate to the propagules and roots after the onset of senescence. This timing mechanism will vary greatly depending on whether the plant is warm or cool season. Warm-season plants will begin senescence later in the year than will C_3 plants.

$CRIT_{8,S}$ - Julian Day that Senescence Ends

The Julian day that senescence is completed ($CRIT_{8,S}$) marks the end of the growing season although regrowth can occur. This parameter will have the same relationship between warm- and cool-season species as $CRIT_{7,S}$. Care should be used when determining this parameter because it is one of the more sensitive parameters for controlling peak standing crop (MacNeil et al. 1985).

PARAMETERS CONTROLLING DECOMPOSITION AND DENITRIFICATION

Control of decomposition rates is accomplished through parameters PNS_1, PNS_2, PNS_3, PNS_5 and PNS_6. Denitrification is controlled by PNS_4. These parameters are not specific for either the simulated sites within a field or the simulated species but specific for a particular locale (with characteristic soils, topography, and so forth), thereby making the values field or pasture specific. Litter decomposition, as opposed to breakdown, is accomplished by soil microflora. The microbial mass consists mainly of fungal mycelia, with quantities on the order of 10 g m^{-2} (Witkamp 1971). Parameters PNS_1 and PNS_2 work against plant production and animal gain. So, increasing these parameters results in a decrease in plant production and subsequent animal gains. The other three parameters serve to increase plant production and animal gains in proportion to the parameter increase. Thus, plant production and animal gain can be increased by increasing PNS_3, PNS_5, or PNS_6, or by decreasing PNS_1 or PNS_2.

Temperature and moisture interact to directly influence organic matter decomposition rates (Volobuev 1964). With adequate mositure, decompositon rates of organic matter increase as temperature increases in the spring cn the shortgrass prairie (Clark and Coleman 1972). Throughout the Great Plains, decomposition rates correlate strongly with incident solar radiation, but rates are generally slower in the Northern Plains (Sims and Singh 1978a).

The parameters PNS_1, PNS_2, and PNS_3 control the percentage of dead roots, litter, and soil organic matter susceptible to decomposition. The best way to set these parameters is to make certain that over long simulation experiments (10 to 50 years), the respective state variables remain roughly constant; that is there are no great losses or gains to the state variable for dead roots, litter, or soil organic matter.

Parameters PNS_5 and PNS_6 control the water-stress dynamics for decomposition. In essence, these parameters are for the microbial colonies present in the soil and are, therefore, used to determine the effect of water stress on all material in the soil mass (dead roots, litter, and soil organic matter). The water potential at which decomposition activity is one-half maximum (PNS_5 in -bars) should have a value below eight for most grassland situations. The drought-tolerance coefficient for decomposition is harder to ascertain. We have been using a value of about 1.2. To calculate this parameter, we must know the decomposition activity for one other point. Suppose we know that the decomposition activity at -20 bars is 0.25, then PNS_6 is:

$$PNS_6 = \frac{\ln\left(\frac{1.0 - 0.25}{0.25}\right)}{\ln\left(\frac{20.0}{8.0}\right)} = 1.2 \tag{2}$$

PARAMETERS CONTROLLING SEED PRODUCTION AND GERMINATION

Parameters $P_{17,S}$, $P_{19,S}$, $CRIT_{5,S}$, and $CRIT_{6,S}$ control seed production and germination. The seed germination component of the SPUR model is merely a place holder. Our justification for including such a simplistic germination model is that, according to the experts, germination of seeds is not a major concern on perennial grassland (the initial target ecosystem for SPUR simulation). Problems with the SPUR germination routine are (1) it assumes that all germination material becomes established (2) it is based on the amount of biomass instead of the number of seeds; and (3) it does not keep track of yearly cohorts of seeds, and, therefore, does not affect those seeds with current weather. We do not recommend relying too heavily on the results from the germination submodel.

$P_{17,S}$ - Photosynthate Translocated to Propagules

The parameter $P_{17,S}$ is the proportion of photosynthate produced during the current simulated day that is sent to the propagule compartment after flower initiation. Propagule biomass is probably quite low for perennial species. Since sexual reproduction is of minor importance on rangeland, the SPUR model can be run using no initial propagule biomass. For annual plants, the initial seed biomass will need to be adjusted to obtain the desired results. Remember, this is a proportion and may also be thought of as a

percentage. Thus, a value of 0.10 means that 10 percent of the current day's photosynthate will be put into the propagule compartment. All standing, green plant tissue is capable of producing propagule biomass. This biomass is assumed to come from the current day's photosynthate rather than retranslocated from previously structural carbohydrates.

$P_{19,S}$ - Germination Proportion

This parameter describes the amount of seed material that can germinate and become green phytomass. This again is at best a rough approximation of what happens. For the user's general information, Ewing and Menke (1983) report that some graminoids produce germinable seeds even under severe drought conditions. They also report minimum seed production at -15 bars in experiments using -1, -7, and -15 bars for germination water potentials.

$P_{23,S}$ - Seed-Mortality Proportion

Parameter $P_{23,S}$ is the proportion of the viable seed biomass which is transferred to the litter box per species on a daily basis. Since the transfer is dependent on the size of the viable seed population, the amount transferred will peak during the growing-season peak production for the species and be lowest when little or no green biomass is being produced. The parameter is fixed for the duration of the simulation experiment and is not altered by moisture or temperature effects.

$CRIT_{5,S}$ - Water Potential for Seed Germination

This parameter sets the water potential for seed germination (bars). The water potential of the seeds themselves during germination of several rangeland grasses has been shown to range from close to 0.0 bars to between -15.0 and -20.0 bars for grasses and from close to 0.0 to about -15.0 bars for forbs (McDonough 1975).

$CRIT_{6,S}$ - Julian Day that Seed Production Begins

Parameter $CRIT_{6,S}$ is the day seed production begins. The user should again consider the nature of the seed germination submodel.

PARAMETERS CONTROLLING MISCELLANEOUS PROCESSES

The following parameters control miscellaneous processes within the SPUR model.

$P_{7,S}$ - Drought-Tolerance Coefficient

The nondimensional drought-tolerance coefficient $P_{7,S}$ controls photosynthesis. We suggest the user leave this parameter unchanged once it has been estimated. Connor et al. (1974) reported the minimum soil-water potential for blue grama photosynthesis of -93.9 bars; a value of less than -70.0 bars was reported from previously published field and laboratory observations. Using -70 bars as a minimum water potential of blue grama, $P_{7,S}$ can be calculated as:

$$P_{7,S} = \frac{\ln\left(\frac{1.0 - 0.001}{0.001}\right)}{\ln\left(\frac{70}{P_{6,S}}\right)} = \frac{6.9068}{\ln\left(\frac{70}{P_{6,S}}\right)} \tag{3}$$

and if $P_{6,S}$ = 25 then

$$P_{7,S} = 6.7081$$

We have been using -50 bars as the minimum water potential for photosynthesis of a typical warm-season grass. Thus:

$$P_{7,S} = \frac{6.9068}{\ln\left(\frac{50}{25}\right)} = 9.96 \tag{4}$$

$P_{10,S}$ - Standing-Dead Wind Tolerance

This parameter determines the ability of the standing dead of a species to withstand lodging by wind. In general the larger the absolute value of this parameter, the lower the amount of breakage of standing dead. Little work has been done to quantify the fracturing of standing dead, so to attain the desired dynamics, the user will need to adjust this parameter for an individual species or species group following a number of simulation experiments.

$P_{11,S}$ - Standing-Dead Precipitation Tolerance

This parameter is similar to $P_{10,S}$ except it sets the strength of a species for lodging by precipitation rather than wind.

$P_{16,S}$ - Phytomass to Leaf-Area Conversion Factor

Parameter $P_{16,S}$ is used to change phytomass ($g\ m^{-2}$) to leaf area index (LAI). (See the discussion of $CRIT_{1,S}$.) Increases in $P_{16,S}$ lead to decreases in deep percolation, evaporation, and plant-available water. The plant production indicators are also reduced causing a reduction in animal weight gain.

There is a high correlation between leaf dry weights and leaf area (Watson 1937, Zrust et al. 1974). A linear relationship derived by Ramo et al. (1983) for winter barley (Hordeum sp.) was:

$$\text{leaf dry matter (g)} = -6.58 + 244.86 \text{ leaf area} \tag{5}$$

with an r^2 of greater than 0.9, For winter wheat (Triticum aestivum), Aase (1978) derived the linear relationship:

$$\text{leaf dry matter (g)} = -28.54 + 201.90 \text{ leaf area} \tag{6}$$

Again the r^2 for this relationship was greater than 0.9. In SPUR, the intercepts for these linear relationships are assumed to be 0.0;

therefore, a simple ratio would be:

$$\text{leaf area} = a \cdot \text{leaf dry matter (g)} \qquad (7)$$

where a equals 0.0041 and 0.0050 for Hordeum sp. and Triticum sp., respectively. The user, in the absence of actual field, literature, or laboratory data, should use a value of about 0.015 for graminoids and 0.03 for forbs and shrubs. Subsequent simulation experiments can be used to adjust these values.

$P_{18,S}$ - Root-to-Shoot Translocation Proportion

This parameter specifies the amount of root biomass that is allowed to be translocated from the roots to the shoots during any one time step. Translocation rates of blue grama have been discussed by Bachelet et al. (1983). The actual proportion of root biomass that can be translocated on a given day is not well known, but we have found that values of 0.5 percent are adequate for the species we have tested. The model is not overly sensitive to this parameter, so the actual value used can vary by a considerable amount before changes in the indicator variable become significant. Increases in $P_{18,S}$ will cause subsequent decreases in plant production and animal performance.

$P_{20,S}$ - Maintenance-Respiration Coefficient

The maintenance-respiration coefficient (mg respired g^{-1} root day^{-1}) was reported as 0.02 mg mg^{-1} day^{-1} (20 mg g^{-1} day^{-1} in the units of SPUR) by Bachelet et al. (1983). In SPUR, we have used values of from about 20 to 70 mg g^{-1} day^{-1}. Increasing $P_{20,S}$ leads to a decrease in plant production with no change in shoot nitrogen content; therefore, subsequent increases in intake and animal gain occur because the percentage nitrogen in the standing green increases.

$P_{21,S}$ - Additional Shoot Death After Senescence

Parameter $P_{21,S}$ is the additional proportion of shoots that die after senescence begins. This parameter is poorly defined in the literature, so values of about 5 percent (0.05) have been used in SPUR. The parameter has a proportional effect on evaporation and transpiration and has an inversely proportional effect on root mortality.

$CRIT_{1,S}$ - Maximum Leaf Area Index of Green Shoots

The parameter designated as $CRIT_{1,S}$ is the maximum leaf area index (nondimensional) allowed for a species. This parameter is used to regulate the leaf area of a simulated plant species. If the leaf area for a species exceeds the value of $CRIT_{1,S}$ for any given simulation day, and if it is before the aboveground part of the plant begins to die, then translocation of biomass from roots to shoots will not occur. If leaf area exceeds this value, and if this occurs after the aboveground portion of the plant begins to die, then any additional photosynthate subsequently produced is transferred to the dead-shoot compartment. Conceptually, a value of 1.0 means that all the ground area is covered by a single layer of plant tissue. A value of 2.0 means the ground is covered by two layers of plant tissue and so forth. If an experiment is done using five plant species, each with a maximum leaf area index of 3.0, then the maximum field index is 15.0.

Measured values of maximum SPUR field-equivalent leaf areas for shortgrass prairie dominated by blue grama (Bouteloua gracilis) in Colorado are 0.55 in 1970 and about 0.40 in 1971 (Knight 1973). For mixed grass prairie in Canada, Coupland et al. (1973) reported for 1970 a peak LAI for green shoots of 2.0 and about 1.0 for 1971. For a tallgrass prairie dominated by bluestem grasses (Andropogon sp.), Conant and Risser (1974) measured a maximum leaf area index of 3.1 for green biomass on ungrazed quadrats. Maximum LAI measurements in crops often are as high as 4.0 (Singh et al. 1980) and values as large as 12.0 have been reported (Pearce et al. 1967).

A value of 3.0 is recommended as a starting point in lieu of actual field or laboratory data. Subsequent model tuning can further resolve the value of this variable. Increasing $CRIT_{1,S}$ causes increases in plant production and decreases in animal-weight gain.

$CRIT_{3,S}$ - Temperature for Root-to-Shoot Translocation

This parameter (°C) represents the average 10-day moving temperature at which translocation from roots to shoots occurs. This important parameter determines when spring growth initiation is to begin. By increasing the parameter, the plant will need a higher spring temperature to initiate growth, thus forcing growth to begin later in the growing season. For this reason, C_4 plants should have a higher $CRIT_{3,S}$ value than C_3 plants. This framework for defining growth initiation is used as an alternative of the degree-day concept because (1) in rangeland situations we do not know when to start collecting degree days and (2) the concept assumes the temperature of deactivation does not occur but on rangeland soils it does. Thus, by using $CRIT_{3,S}$ we are able to determine the initiation of growth based purely on the environment for the particular year being simulated. Values range from below 5 °C for some C_3 perennials to more than 12 °C for warm season grasses, such as blue grama.

$CRIT_{4,S}$ - Water Potential for Root-to-Shoot Translocation

The parameter $CRIT_{4,S}$ is the water potential for translocation of biomass from the roots to shoots and works in much the same way as $CRIT_{3,S}$, but it has less control over the indicator variables shown in table 5.5. The purpose of this parameter is to separate drought-tolerant from drought-susceptible species. We have been running SPUR using values of about -8.0 bars for cool-season plants and shrubs, and about -12.0 bars for warm-season plants. Grasses are considered to be slightly more drought tolerant than forbs and shrubs.

PRESET AND UNUSED PARAMETERS

$P_{8,S}$ - Photosynthate Translocated to Roots After Senescence

The proportion of photosynthate translocated to the roots from the shoots ($P_{8,S}$) is a rather trivial parameter. Indeed we have found little use for including it as a parameter; it should, therefore, remain constant. A value of 0.7 has been used throughout SPUR development. Porter (1966) estimated that 40 percent of the carbon fixed by a plant remains in the fixation leaves, 10 percent is sent to developing leaves, 25 percent is sent to the stem, and the remainder is translocated to the roots. The SPUR plant model does not distinguish between old or new leaves or stems, so roughly 25 percent of the carbon fixed in a SPUR simulation by each plant species is sent to the roots. Also, according to Ryle (1970), more carbon is placed in stems by annuals than perennials which put larger portions of carbohydrates into roots.

$P_{12,S}$ - Susceptibility of Green Shoots to Trampling

Proportion of phytomass susceptibile to trampling is used primarily to distinguish between herbaceous vegetation and shrubs. In SPUR, the woody portion of shrubs is treated as standing dead. Thus, by giving $P_{12,S}$ a value near zero, the effect of large-grazing herbivores is eliminated.

$P_{13,S}$ - Susceptibility of Standing Dead Shoots to Trampling

The proportion of standing dead susceptible to trampling is again a parameter used to distinguish between herbaceous vegetation and shrubs. The same statements made concerning $P_{12,S}$ apply here.

$P_{22,S}$ - Unused Parameter

Parameter $P_{22,S}$ is not used in SPUR.

ECOTYPES

Plant ecotypes are locally adapted populations of plant species and represent genetic plasticity within a species population. Some members of a species may inhabit the xeric south or west facing slopes, for example, while other members may grow and thrive on more mesic north or east facing slopes. The two groups represent physiological adaptations to different environments over the range of the species. The literature contains many examples of ecotypes. Mooney and Billings (1961) and Mooney and Johnson (1965) have shown physiological distinctions between populations of *Oxyria digyna* and *Thalictrum alpinum*. Working in California, Cole (1967) found different rates of CO_2 exchange and transpiration associated with habitat differences in several species of *Eriogonum*. Squillace and Bingham (1958) found local ecotypic variation in *Pinus monticola* based on moisture and elevation of the site of origin. Hanson (1982) discussed the ecological implication that *Prosopis gladulosa* var. *glandulosa*, grown from seeds collected in west Texas, had a lower light-use efficiency than comparable seeds from east Texas. Mooney and Billings (1965), using perennial rhizomatous species in the Rocky Mountains and the Sierra Nevada, found the highest carbohydrate levels in the plants from the lowest elevations. And Skiles (1971) demonstrated photosynthesis and respiration variations in seedlings of *Artemisia tridentata* acclimated to different temperature regimes.

So, grasses, forbs, shrubs, and trees can exhibit marked ecotypic and, thus, physiological differences among members of the same species. The importance to the SPUR user is if these differences are significant, according to the criteria of the user, different sets of parameters must be developed to use the model. Thus, for example, if two ecotypes of blue grama, one adapted to bottomlands and one adapted to hillsides, have different productivity dynamics, then they cannot be lumped together as blue grama in any given simulation experiment. Rather, they must be entered as two distinct species.

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6. HYDROLOGY-COMPONENT PARAMETER ESTIMATION

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INTRODUCTION

The hydrology submodel of SPUR is divided into three basic components: the upland, snow accumulation and melt, and channel components. Parameter estimation will be described for each of these components. The user is referred to table 3.3 in chapter 3, for the appropriate record numbers, variables, name and variable descriptions for these components.

THE UPLAND COMPONENT

The upland hydrology routines are basically the option-1 water balance routines from the CREAMS model (Knisel 1980). The condition-I curve number (CN_I), variable S1 on record 10, can be obtained from tables 6.1 and 6.2 which are curve numbers for rangeland watersheds and range sites from Hanson et al. (1980). If the SCS Hydrology Handbook is used, a condition-II CN is obtained. This can be converted to CN_I by the equation presented by Smith and Williams (1980).

The return-flow time (T_r), variable S2 on record 10, is the time required for subsurface flow from the centroid of the basin to reach the outlet. This parameter is important in snow-dominated regions where sustained baseflow occurs. Springer et al. (1984) calibrated this parameter on three experimental watersheds within the Reynolds Creek Experimental Watershed and found values that ranged from 5 to 40 days. The values vary because of the different hydrologic and geologic factors governing watershed response. Currently, we suggest that values for this parameter be determined by a hydrologist experienced with the flow characteristics of the region or through model calibration if data are available.

Four other parameters on record 10 are the Universal Soil Loss Equation (USLE) factors for the MUSLE calculations. These factors are defined and tables are given in Wischmeier and Smith (1978).

The USLE K factor (FLDK) is determined by using the nomograph in figure 6.1. Texture values required to enter the nomograph can be found in soil survey manuals or through the SCS Soils-5 database. The Soils-5 database is described in more detail below.

The USLE C factor (FLDC) can be estimated from table 6.3 (table 10, Wischmeier and Smith 1978). The USLE P factor (FLDP) is set to 1.0 for current simulations. The USLE slope-length factor (FLDLS) is critical for sediment yield calculations (Renard et al. 1983). The Grid-Contour method (Williams and Berndt 1976) is recommended for determining the slope. Average slope is calculated using a contour map and the following equations:

$$S_d = N_d \frac{H}{D_d} \quad (1)$$

$$S = \left[S_l^2 + S_w^2\right]^{\frac{1}{2}} \quad (2)$$

where:

S_d = slope in the d grid direction,
S = average land slope,
N_d = total number of contour crossings from all grid lines in direction d,
H = contour interval,
D_d = total length of all grid lines within the field in direction d,
S_l = slope in the length grid direction from equation 1, and
S_w = slope in the width direction from equation 1.

The average slope length is found by the Contour-Extreme Point Method (Williams and Berndt 1976) using:

$$L = \frac{LC}{2EP} \quad (3)$$

where:

EP = number of extreme points (channel crossings) on the contours of a topographic map,
LC = total length of all contours within the area, and
L = average slope length.

The variable FLDLS is computed by:

$$FLDLS = \left[\frac{L}{72.6}\right]^m [65.41 \sin^2(S) + 4.56 \sin(S) + 0.065] \quad (4)$$

where:

S = slope of the site,
L = slope length of the site, and
m = an exponent proportional to slope steepness.

The exponent m varies with slope and is determined by:

$$m = 0.6\ (1 - e^{-35.835\, S}) \quad (5)$$

where S = slope.

The rooting depth, RD on record 11, is the effective depth over which plants can extract water by transpiration. Any value for RD must be less than the depth to the top of the last soil layer. Values for RD can be obtained from SCS soil surveys.

The soil evaporation parameter, CONA on record 11, has the following values suggested by Ritchie (1972): for a loam soil, 4.5, clay soil, 3.5, and 3.3 for sands (all values are in mm/day$^{1/2}$).

Table 6.1
Runoff curve numbers derived from range sites and conditions of cover for antecedent moisture condition I

Range site	Range condition		
	Poor	Fair	Good
Wetland	95	95	95
Very shallow	95	90	85
Saline subirrigated	90	90	85
Subirrigated	90	90	85
Shale	90	85	80
Dense clay	90	85	80
Alakali clay	90	85	80
Saline upland	90	85	80
Igneous	90	80	75
Shallow clayey	85	80	75
Shallow sandy	80	75	70
Shallow loamy	80	75	70
Shallow igneous	80	75	70
Steep clayey	80	75	70
Clayey	80	75	65
Gravelly loamy	80	75	65
Steep loamy	80	75	65
Overflow	80	70	60
Loamy overflow	80	70	60
Clayey overflow	80	70	60
Coarse upland	80	70	60
Limy upland	80	70	60
Shallow breaks	80	70	60
Stony	80	70	60
Steep stony	80	70	60
Lowland	80	70	60
Saline lowland	80	70	60
Loamy lowland	80	65	55
Loamy	80	65	55
Sandy lowland	75	60	50
Sandy	75	60	50
Gravelly	70	55	45
Sands	70	55	40
Choppy sands	70	55	40

Note.--As site conditions are general, the curve number should be adjusted (interpolated) for each site based upon a field investigation.

Table 6.4 was taken from Lane and Stone (1983) and provides values for CONA by soil-texture class.

Crack flow is used to simulate water movement for unsaturated soil conditions. The crack-flow factor, CF on record 12, is a decimal ranging from 0.0 to 1.0. There is little if any experience with this parameter in rangeland situations.
If CF is set to 0.0, the only water movement will be by percolation when the water content of a soil layer is greater than field capacity. For most situations, this will be adequate. If there is substantial water movement by cracks or under unsaturated conditions, CF will need to be calibrated.

Records 13 to 17 are data for each soil layer. These data are essential for the primary producer (plant) routines. On rangelands, these data are often lacking so an estimation procedure is required. The advent of the SCS Soils-5 database has given users an opportunity to obtain representative values for these parameters. For access to Soils-5 data, the user should contact the local SCS office. In addition to providing soils information required on records 13 through 17, Soils-5 can be used to help estimate the USLE factors previously discussed.

Much of the following discussion uses table 6.5 which was taken from Brakensiek et al. (1984) and Rawls and Brakensiek (1985). The boldface letters over each column identify a property to be used in the following calculations.

From column A the total number of soil layers, NMSL on record 10, and the depth of each soil layer, SLDTH on record 17, can be found. The maximum number of soil layers allowed is eight. A requirement for the plant production routines is the soil-water potential at 15.0 cm (6.0 in) in the soil profile. It was discovered that by

Table 6.2
Soil Conservation Service curve numbers from selected USDA-ARS watersheds in the northern Great Plains

Watershed location	Watershed number	Area (acres)	Range type	Range condition	Hydrologic group	SCS curve No. Low	Av.	High
Hastings, NE	1H	3.62	Native meadow	Fair	B	40	50	88
Hastings, NE	2H	3.40	Native meadow	Fair	B	41	61	87
Hastings, NE	18H	3.74	Native pasture (heavy grazing).	Fair	B	63	80	96
Ekalaka, MT	1	2.00	Saline-upland range site.	Poor	D	86	93	99
Ekalaka, MT	2	2.00	Panspots	Poor	D	82	87	98
Ekalaka, MT	3	2.00	Panspots	Poor	D	80	89	97
Cottonwood, SD	4H	8.57	Pierre shale (heavy grazing).	Fair	D	55	71	95
Cottonwood, SD	5M	8.57	Pierre shale (medium grazing).	Fair	D	57	70	94
Cottonwood, SD	6L	8.99	Pierre shale (light grazing).	Good	D	53	67	94
Newell, SD	2	115.00	Medium-textured soils (mixed range sites).	Poor	B	52	70	89
Newell, SD	55	41.40	Medium-textured soils (mixed range sites).	Fair	B	50	61	94
Newell, SD	7	160.00	Medium-textured soils (mixed range sites).	Poor	B	55	63	93
Newell, SD	12	90.00	Fine-textured soils (mixed range sites).	Poor	D	71	89	98
Newell, SD	13	60.00	Fine-textured soils (mixed range sites).	Poor	D	57	81	96
Newell, SD	14	35.00	Fine-textured soils (mixed range sites).	Poor	D	66	77	94
Newell, SD	15	115.00	Fine-textured soils (mixed range sites).	Poor	D	66	77	93
Newell, SD	51	7.90	Sandy range sites.	Fair	B	52	61	81
Newell, SD	53	11.30	Sandy range sites.	Fair	B	42	46	86
Newell, SD	55	16.50	Sandy range sites.	Fair	B	45	50	95
Newell, SD	P5	8.00	Panspots	Fair	D	64	76	96
Newell, SD	P6	13.20	Panspots	Fair	D	63	73	90
Newell, SD	P7	7.25	Panspots	Fair	D	65	81	97
Newell, SD	P8	6.42	Panspots	Fair	D	72	82	91
Newell, SD	P9	6.96	Panspots	Fair	D	71	82	95
Aladdin, WY	1	7.70	Silty range site.	Fair	D	61	75	89
Aladdin, WY	2	8.20	Silty range site.	Fair	D	61	74	86
Aladdin, WY	3	11.60	Shallow range site.	Fair	D	71	75	95
Aladdin, WY	4	2.50	Shallow range site.	Fair	D	72	82	95
Reynolds, ID	1	205.00	Summit watershed (mixed range site).	Poor	D	74	75	86
Reynolds, ID	2	33.00	Lower Sheep (mixed range site).	Poor	D	74	75	86

Table 6.2--Continued
Soil Conservation Service curve numbers from selected USDA-ARS watersheds in the northern Great Plains

Watershed location	Watershed number	Area (acres)	Range type	Range condition	Hydrologic group	SCS curve No. Low	Av.	High
Reynolds, ID	3	306.00	Murphy (mixed range site).	Fair	C	69	70	91
Reynolds, ID	4	100.00	East Reynolds Mt. (mixed range site).	Fair	C	79	82	88
Guthrie, OK	W-I	2.50	Virgin native grass.	Good	B	33	68	95
Guthrie, OK	W-II	5.09	Virgin native grass.	Good	B	32	61	85
Guthrie, OK	W-III	9.09	Formerly cultivated; eroded.	Fair	B	56	78	98
Guthrie, OK	W-IV	13.40	Formerly cultivated; eroded.	Fair	B	53	78	98
Guthrie, OK	W-V	15.70	Formerly cultivated; eroded.	Fair	B	55	81	96
Guthrie, OK	PL, L	5.62	Native woodland	Fair	B	30	59	95
Guthrie, OK	PL, J	5.28	Severely eroded	Poor	B	53	78	93
Guthrie, OK	PL, 15A	3.13	Formerly cultivated; terraced.	Good	B	55	81	96
Guthrie, OK	PL, 13	3.21	Gullied: reformed	Good	B	58	81	98
Chickasha, OK	R-2	24.08	Sandy range site	Fair	B	45	68	86
Chickasha, OK	R-5	23.72	Virgin rangeland site.	Good	D	41	76	98
Chickasha, OK	R-7	19.19	Formerly cultivated; treated.	Poor	D	52	83	98

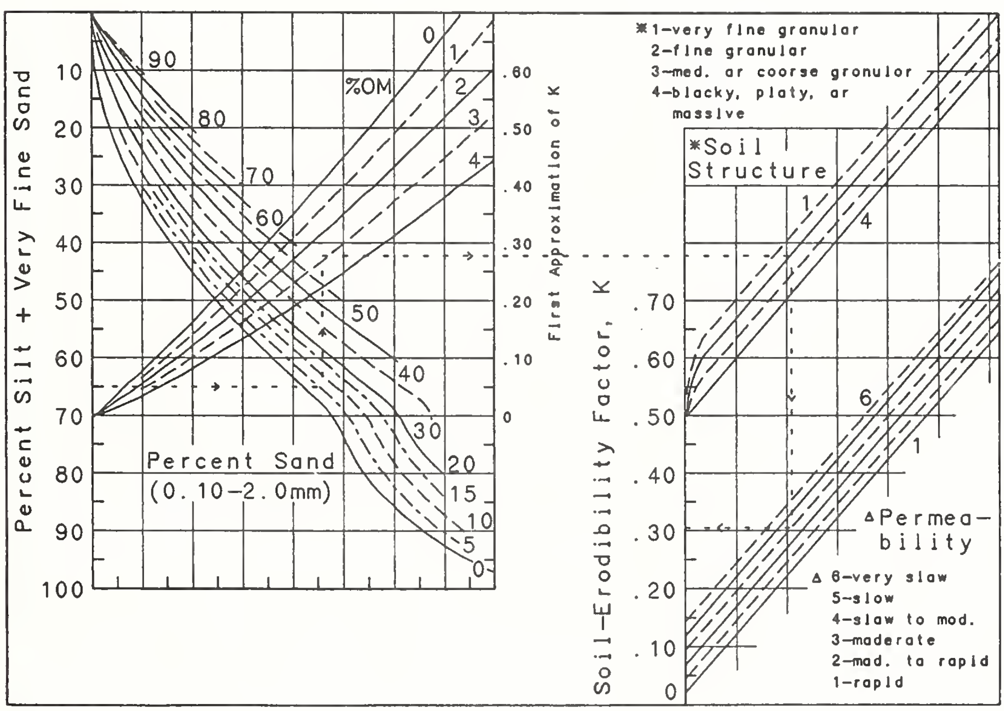

Figure 6.1
The soil-erodibility nomograph.

Table 6.3
Factor C for permanent pasture, range, and idle land[1/]

Vegetative canopy		Cover that contacts the soil surface (percent ground cover)						
Type and height[2/]	Percent cover[3/]	Type[4/]	0	20	40	60	80	95+
No appreciable canopy.		G	0.45	0.20	0.10	0.042	0.013	0.003
		W	.45	.24	.15	.091	.043	.011
Tall weeds or short brush with average drop fall height of 20 in.	25	G	.36	.17	.09	.038	.013	.003
		W	.36	.20	.13	.083	.041	.011
	50	G	.26	.13	.07	.035	.012	.003
		W	.26	.16	.11	.076	.039	.011
	75	G	.17	.10	.06	.032	.011	.003
		W	.17	.12	.09	.068	.038	.011
Appreciable brush or bushes with average drop fall height of 6 1/2 ft.	25	G	.40	.18	.09	.040	.013	.003
		W	.40	.22	.14	.087	.042	.011
	50	G	.34	.16	.08	.038	.012	.003
		W	.34	.19	.13	.082	.041	.011
	75	G	.28	.14	.08	.036	.012	.003
		W	.28	.17	.12	.078	.040	.011
Trees, but no appreciable low brush. Average drop fall height of 13 ft.	25	G	.42	.19	.10	.041	.013	.003
		W	.42	.23	.14	.089	.042	.011
	50	G	.39	.18	.09	.040	.013	.003
		W	.39	.21	.14	.087	.042	.011
	75	G	.36	.17	.09	.039	.012	.003
		W	.36	.20	.13	.084	.041	.011

1/ The listed C values assume that the vegetation and mulch are randomly distributed over the entire area.

2/ Canopy height is measured as the average fall height of water drops falling from the canopy to the ground. Canopy effect is inversely proportional to drop fall height and is negligible if fall height exceeds 33 ft.

3/ Portion of total-area surface that would be hidden from view by canopy in a vertical projection (a bird's-eye view).

4/ G: Cover at surface is grass, grasslike plants, decaying compacted duff, or litter at least 2 in deep. W: Cover at surface is mostly broadleaf, herbaceous plants (as weeds with little lateral-root network near the surface) or undecayed residues or both.

making the top layer 15.0 cm thick, the soil water tensions fluctuated rapidly from day to day causing unrealistic responses in the plant component. To remove the impact of moisture inputs of relatively small magnitude, the soil between 0 and 15.0 cm should be divided into two layers. The preferred thickness for each layer is 7.5 cm (3.0 in). This provides a smoother response of the soil-water tension and a more appropriate response of the plant component.

Porosity, SMO on record 13, can be determined by using the bulk density in column N of table 6.5, assuming a particle density of 2.65 g/cm^3, and by using the following equation:

$$SMO = 1.0 - \frac{BD}{2.65} \tag{6}$$

where:

SMO = porosity,
BD = bulk density (g/cm^3), and
2.65 = assumed particle density (g/cm^3).

Soils-5 presents a range of values for many of the properties including bulk density, and at this time we cannot provide any rules as to how best to choose a value for simulation. Once a value has been chosen, that is, the upper limit, lower limit, or a mid-range value, the user should be

Table 6.4
Selected soil properties based on soil texture class

Soil texture class	Representative composition			Saturated-soil hydraulic conductivity (cm/hr)			Bare-soil evaporation parameter (c) (mm/day $^{1/2}$)		
	Clay	Silt	Sand	Avg	Low	High	Avg	Low	High
Sand	3	7	90	23.0	11.7	43.2	3.3	3.05	3.32
Loamy sand	5	15	80	6.1	3.6	11.7	3.3	3.05	3.32
Sandy loam	10	20	70	2.2	1.7	3.6	3.5	3.10	4.06
Loam	20	40	40	1.3	0.91	1.7	4.5	3.20	4.57
Silt loam	15	65	20	0.69	0.46	0.91	4.5	3.20	4.57
Silt	5	87	8	0.51	0.30	0.61	4.0	3.15	4.40
Sandy clay loam	30	10	60	0.30	0.25	0.46	3.8	3.15	4.32
Clay loam	35	35	30	0.20	0.19	0.25	3.8	3.15	4.32
Silty clay loam	35	55	10	0.18	0.15	0.19	3.8	3.15	4.32
Sandy clay	45	5	50	0.13	0.11	0.15	3.4	3.10	3.56
Silty clay	45	50	5	0.10	0.09	0.11	3.5	3.10	3.81
Clay	65	20	15	0.08	0.06	0.09	3.4	3.10	3.56

Source.--Lane and Stone (1983).

consistent for all other properties. Lane and Stone (1983) present values for porosity by texture classes (table 6.6).

There are two possible ways to obtain values for saturated hydraulic conductivity, SLSC on record 16, using Soils-5 output. Column O in table 6.5 is the range of permeability of the soil and this can be used. Another technique was presented by Brakensiek et al. (1984) and Rawls and Brakensiek (1985) which uses the relationship between soil texture and saturated hydraulic conductivity. The equations are:

$$\begin{aligned}\ln K_s = {} & 19.52348\ SMO - 8.96847\ PC + \\ & 0.00018107\ PS^2 - 0.0094125\ PC^2 - \\ & 8.295215\ SMO^2 + 0.077718\ PS\ SMO - \\ & 0.00298\ PS^2 SMO^2 - \\ & 20.019492\ PC^2\ SMO^2 + \\ & 0.0000173\ PS^2\ PC + \\ & 0.02733\ PC^2\ SMO + 30.001434\ PS^2 - \\ & 0.0000035\ PC^2\ PS\end{aligned} \tag{7}$$

$$SLSC = 2.54\ e^{\ln K_s} \tag{8}$$

where:

SMO = porosity from equation 6,
PC = percent clay,
PS = percent sand,
$\ln K_s$ = natural log of saturated soil-hydraulic conductivity, and
K_s = saturated hydraulic conductivity.

From table 6.5, the percentage of clay is available in column M, and SMO can be calculated from equation 6. Percentage of sand is not available in the Soils-5 output, but it can be calculated from relationships derived by R.B. Grossman of the SCS National Soil Survey Laboratory, Lincoln, Nebraska, for the Soils-5 database. Grossman's equation for percent sand is:

$$PS = 100 - \frac{100\ I}{G} \tag{9}$$

where:

PS = percent sand,
I = value from column I of table 6.5, and
G = value from column G of table 6.5.

Once PS is determined, equations 7 and 8 can be solved to provide the saturated soil-hydraulic conductivity.

If a texture classification is used, table 6.4 from Lane and Stone (1983) can be used to determine a value for SLSC. Values should be converted to inch per hour for input to SPUR.

The volumetric water contents at 1/3-bar (SM3) and 15-bar (SM15) tensions, records 14 and 15 in chapter 3, table 3.3, can also be determined using relationships presented by Grossman for Soils-5 data or from Brakensiek et al. (1984). Brakensiek et al. (1984) proposed the following equations based on soil texture:

$$\begin{aligned}SM3 = {} & 0.1535 - 0.0018\ PS + 0.0039\ PC + \\ & 0.1943\ SMO\end{aligned} \tag{10}$$

and:

$$\begin{aligned}SM15 = {} & 0.0370 - 0.0004\ PS + 0.0044\ PC + \\ & 0.0482\ SMO\end{aligned} \tag{11}$$

where:

SM3 = 1/3-bar volumetric soil water content (decimal fraction),
SM15 = 15-bar volumetric soil water content (decimal fraction),
PS = percent sand,
PC = percent clay, and
SMO = porosity.

Table 6.5
SOILS-5 file for Searla soil series

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SEARLA (ID0929)COOL

MLRA(S): 25
REV. TH,GHL , 12-82
CALCIC ARGIXEROLLS, LOAMY-SKELETAL, MIXED, FRIGID

THE SEARLA SERIES CONSISTS OF VERY DEEP WELL DRAINED SOILS THAT FORMED IN COLLUVIUM FROM SEDIMENTARY ROCKS ON MOUNTAINS. ELEVATION IS 5500 TO 6900 FEET. AAP IS 14 TO 16 INCHES. MAST IS 42 TO 45 F. FFS IS 50 TO 70 DAYS. VEGETATION IS MOUNTAIN BIG SAGEBRUSH AND BLUEBUNCH WHEATGRASS. TYPICALLY THE SURFACE LAYER IS BROWN GRAVELLY LOAM 15 INCHES THICK. THE SUBSOIL IS YELLOWISH BROWN VERY GRAVELLY CLAY LOAM TO 32 INCHES. THE SUBSTRATUM IS WHITE VERY GRAVELLY LOAM AND VERY PALE BROWN VERY GRAVELLY SANDY LOAM TO 60 INCHES. SLOPES ARE 30 TO 60 PERCENT.

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SEARLA (ID0929)COOL

A	B	C	D	E	F	G	H	I
DEPTH (IN.)	TEXTURE	UNIFIED	AASHTO	FRACT > 3IN (PCT)	PERCENT OF MATERIAL LESS THAN 3 IN PASSING SIEVE NO.			
					4	10	40	200
0-15	GR-L	SM-SC,GM-GC	A-4	5-10	65-85	60-80	45-60	35-50
15-32	GRV-CL	GC	A-2	5-15	45-60	35-50	25-40	20-35
32-60	GRV-L,GRV-SL	GM-GC	A-1,A-2	0-15	35-60	25-50	15-35	10-30

J	K	M	N	O	P	Q	R
LIQUID LIMIT	PLAST'Y INDEX	CLAY %<2MM	MOIST BULK DENSITY (G/CM3)	PERMEA-BILITY (IN/HR)	AVAILABLE WATER (IN/IN)	SOIL REACTION (PH)	SALINITY MMHOS/CM
25-30	5-10	12-20	1.40-1.50	0.6-2.0	0.13-0.16	6.6-7.3	-
30-40	10-15	27-35	1.40-1.50	0.2-0.6	0.10-0.13	6.6-7.3	-
25-30	5-10	10-22	1.50-1.60	0.6-2.0	0.05-0.09	7.4-8.4	< 2

S	T	U	V	W
SHRINK-SWELL	EROSION FACTORS		WIND EROD. GROUP	ORGANIC MATTER (PCT)
	K	T		
LOW	.15	2	6	2-4
LOW	.10			
LOW	.05			

Table 6.6
Porosity (percent) and water holding capacity (water content in percent by volume) based on soil texture class

Soil texture class	Total porosity			-1/3-bar Water holding capacity			-15-bar Water holding capacity		
	Avg	Low	High	Avg	Low	High	Avg	Low	High
Sand	41	39	43	9	7	15	3	2	6
Loamy sand	43	39	45	12	10	20	6	4	8
Sandy loam	45	39	52	20	14	29	9	5	12
Loam	47	45	52	26	20	36	12	9	18
Silt loam	50	49	55	31	20	36	13	7	20
Silt	51	49	55	28	26	30	9	6	12
Sandy clay loam	42	38	45	27	17	34	17	11	21
Clay loam	47	40	51	34	29	38	20	16	34
Silty clay loam	47	46	51	36	33	40	21	18	24
Sandy clay	42	40	44	31	27	40	21	18	30
Silty clay	48	46	49	40	35	46	27	23	32
Clay	49	44	52	42	34	49	29	23	38

Source.--Lane and Stone (1983).

Again, Soils-5 can be used to provide the necessary information.

Grossman uses the relationship between 15-bar water content by weight and percent clay:

$$SM15 = \frac{.04\ M\ N}{100} \qquad (12)$$

where:

SM15 = 15-bar volumetric water content,
M = percent clay (PC) from column M of table 6.5, and
N = bulk density from column N of table 6.5.

The ratio of 0.4 of percent clay to 15-bar water content by weight is discussed by NSSL (1983) and this guide should be consulted for situations in which this ratio does not apply. The field capacity or 1/3-bar water content is found by using the following relationships:

$$SM3 = \frac{P}{1 - \frac{Z2}{100}} + SM15 \qquad (13)$$

where:

SM3 = 1/3-bar volumetric soil water content,
P = available water from column P of table 6.5,
Z2 = volume > 2 mm, see equation 14, and
SM15 = 15-bar volumetric soil water content.

A value for Z2 is computed as:

$$Z2 = \frac{Z1}{D_P > 2} \left[\frac{100}{\frac{Z1}{D_P > 2} \frac{100 - Z1}{N}} \right] \qquad (14)$$

where:

Z2 = volume > 2 mm,
Z1 = weight percentage > 2 mm,
D_p>2 = particle density for particles > 2mm (g/cm^3), and
N = bulk density for column N of table 6.5.

The equation to calculate Z1 is:

$$Z1 = E + (1 - \frac{E}{100})(100 - G) \qquad (15)$$

where:

Z1 = weight percentage > 2 mm,
E = fraction > 75 mm from column E of table 6.5, and
G = value from column G of table 6.5.

The particle density for particles greater than 2 mm is 2.65 g/cm^3 unless the organic matter content is greater than 5 percent. If this limit is exceeded, D_p>2 can be determined by the following formula:

$$D_P > 2 = 2.65 \left[\frac{100 - W\,(1 - \frac{Z1}{100})}{100} \right] + \frac{1.4\ W}{100} (1 - \frac{Z1}{100}) \qquad (16)$$

where:

D_p>2 = particle density for > 2 mm fraction (g/cm^3),
W = organic matter percentage column W in table 6.5, and
Z1 = weight percentage > 2 mm; see equation 15.

Another method to derive 1/3-bar water content uses data from table 6.5 and ratios presented in table 6.7. Table 6.7, obtained from NSSL (1983), expresses the ratio between percent silt and available water. Available water is in column P in table 6.5 and percent silt can be calculated by subtracting the sum of percent clay and sand from 100.0. The 1/3-bar water content is determined as:

$$SM3 = (PSI\ RA\ N) + SM15 \qquad (17)$$

where:

- SM3 = 1/3-bar volumetric soil water content,
- PSI = percent silt,
- RA = ratio value from table 3.8,
- N = bulk density (g/cm^3), and
- SM15 = 15-bar volumetric soil water content.

For texture classes, table 6.6 from Lane and Stone (1983) has values listed for both 1/3-bar and 15-bar water contents. These relationships will help the user when field data cannot be obtained. The previous formulas do not and should not be used to remove the necessity of data collection which will provide the best results for any particular site in question.

THE SNOW ACCUMULATION AND MELT COMPONENT

The HYDRO-17 model used to calculate snow accumulation and melt for SPUR is applied to each field in the basin-scale version of the model. The model was developed by Anderson (1973) and is part of the National Weather Service River Forecast Model. The following material was taken primarily from Anderson (1973).

Anderson defines six major and six minor parameters for HYDRO-17. These parameters are input to SPUR on records 19 and 20. Record 21 is the initial snow water equivalent present on a field at the start of a simulation. The major parameters are SCF, MFMAX, MFMIN, UADJ, SI, and an areal depletion curve. The minor parameters are NMF, TIPM, PXTEMP, MBASE, PLWHC, and DAYGM.

The snow-catch correction factor (SCF) is used to adjust precipitation gauge-catch amount for deficiencies in snowfall catch. The value is dependent on wind speed and the exposure of a site. Also, Anderson noted that SCF could be used to implicitly account for gains and losses in the snow water equivalent that are not included in the model, for example, vapor transfer, drifting, and interception. He suggested two methods for determining SCF from data. The first uses wind data and the exposure of each site, and the second uses a dual-gauge site with one shielded and another unshielded precipitation gauge at a site.

When information was not available, Anderson recommended a value of 1.2 for SCF. This represented a protected site with moderate winds during a snow event. More-protected sites would approach a value of 1.0, and less-protected sites would be considerably above the 1.2 value.

Table 6.7
Guides for estimating available water capacity (prepared by STSC)

Soil texture class	Western States 1/	Nebraska 2/ data	Tennessee 3/ West	Tennessee 3/ East	Oklahoma 4/ guides	Louisiana 5/ mean values	Suggested values 6/
Coarse sand & gravel	0.05-0.07	0.03-0.05			0.02-0.06		0.02-0.05
Sands		0.02-0.08				0.05	0.02-0.06
Fine sand	0.05-0.07				0.04-0.06		0.05-0.08
Loamy sand	0.06-0.08	0.07-0.12	0.05-0.09		0.06-0.09		0.06-0.10
Loamy fine sand	0.08-0.11				0.06-0.09	0.08	0.07-0.11
Sandy loam	0.11-0.13	0.12-0.15		0.10-0.16	0.09-0.13	0.12	0.10-0.14
Fine sandy loam	0.13-0.15	0.15-0.18		0.17-0.24	0.09-0.13	0.14	0.11-0.15
Very fine sandy loam	0.15-0.17				0.12-0.16	0.22	0.13-0.20
Loam	0.16-0.18	0.19-0.23		0.19-0.03	0.12-0.16	0.18	0.15-0.20
Silt loam (not loess)	0.19-0.21			0.20-0.03	0.14-0.18	0.23	0.16-0.24
Silt loam (loess), silt		0.23-0.26	0.27-0.05				0.22-0.28
Sandy clay loam	0.14-0.16				0.12-0.16	0.15	0.12-0.17
Clay loam	0.19-0.21	0.21-0.22		0.17-0.03	0.15-0.19	0.17	0.15-0.20
Silty clay loam	0.19-0.21	0.22-0.26	0.25-0.04	0.18-0.04	0.15-0.19	0.21	0.18-0.22
Sandy clay	0.15-0.17				0.14-0.18	0.17	0.14-0.18
Silty clay	0.15-0.17	0.15-0.17		0.19-0.04	0.14-0.18	0.18	0.14-0.18
Clay	0.14-0.16	0.13-0.15		0.15-0.03	0.14-0.18	0.19	0.12-0.18

1/ Guides developed in Western States.
2/ Jordan, R.H., Available water capacity for Nebraska soils, (unpublished).
3/ Longwell, T.J., W.L. Parken, and M.E. Springer, 1963, Moisture characterization of Tennessee soils, Agricultural Experiment Station Bulletin 367.
4/ Guides developed from Oklahoma data.
5/ Guides developed from many sources currently in Louisiana.
6/ Guides based on the data in this table plus other data from States in the Southern Region.

Rangelands are often windswept and open areas and should probably fall in the latter category.

The maximum- and minimum-melt factors (MFMAX and MFMIN) are used to calculate snowmelt for nonrain periods. In HYDRO-17, the computational interval is 6 hours so temporal variations in temperature and precipitation can be accommodated. The SPUR model uses daily values. The extrapolation from 6.0-hour parameter values to 24.0-hour values is not known at this time. Table 6.8 is from Anderson and provides values for both MFMAX and MFMIN for different cover conditions for 6-hour intervals.

The wind function UADJ on record 19 can be computed from wind speeds during rain-on-snow events and the following equation:

$$UADJ = 0.0002\ WIND \tag{18}$$

where:

UADJ = the average wind function using measurements taken 1.0 meter above the snow surface (mm/mb), and

WIND = daily wind movement at 1.0 meter (km).

Anderson (1973) indicated that values for UADJ should range from 0.03 to 0.19 mm/mb with the lower values in forested areas and higher values in open areas.

The variable SI is the maximum accumulation above which there is 100 percent snow cover. Determining this value requires knowledge of snow water equivalent and areal snow cover relationships for several years, and these data are not generally available. Currently, SI is set to a very high value. This allows the annual accumulated maximum snow water equivalent to control the areal depletion curve. Users should be cautioned in setting the value for SI too low since this affects the areal depletion curve and snowpack processes.

A single parameter, ADPT on record 19, parameterizes the areal depletion curve. The five general shapes of areal depletion curves can be seen in figure 6.2. Each number on figure 6.2 corresponds to a value for ADPT. This variable, ADPT, can also be fractional which results in the interpolation between primary ADPT curves. An ADPT value of 3.5 will produce an essentially straight line. If ADPT exceeds 5, the curve for 5 will be used. If ADPT is less than 1, the curve for 1 will be used. The shape of an areal depletion curve is dependent on topography, prevailing wind direction, and snowfall amount, and there are almost no rules for its selection. The user will need to be qualitatively familiar with snow accumulation and melt characteristics for the site to select the proper shape.

The negative melt factor (NMF) and antecedent-temperature parameter (TIPM), both on record 19, control energy exchange during snowmelt periods. The variable, TIPM, weights previous air temperatures for calculation of current snowpack temperature. A low value of TIPM gives more weight to temperatures from previous computational periods. Anderson (1973) suggested a value of 0.5 for TIPM. The variable NMF controls the heat flow into the snowpack and has a recommended value of 0.15 mm/ °C/6-h.

Table 6.8
Typical values of melt factors as related to forest cover for areas with distinct accumulation and melt seasons (units are mm $°C^{-1}$ 6 hr^{-1}).

Forest cover	MFMAX	MFMIN
Coniferous forest - quite dense	0.5 - 0.8	0.2 - 0.3
Mixed forest - coniferous plus open and/or deciduous	0.8 - 1.0	0.25 - 0.4
Predominantly deciduous forest	1.0 - 1.3	0.35 - 0.5
Open areas	1.3 - 2.0	0.5 - 0.9

Source.--Anderson (1973).

The base temperature above which snowmelt will occur during nonrain periods is MBASE and is on record 20. A value of 0.0 °C has been found to be adequate. The variable PXTEMP on record 20 differentiates rain from snow and can range from 0.0 to 2.0 °C (Anderson 1973). At higher elevations snow occurs at temperatures of 3.0 to 5.0 °C.

The percent liquid-water holding capacity for ripe snow, PLWHC on record 20, is generally between 0.02 to 0.05 (Anderson 1973).

The daily groundmelt, DAYGM on record 20, is a constant which represents average daily melt during an average winter. For regions with frozen soils, the value should be close to zero and for areas with relatively mild winters and deep snow cover, for example, the Sierra Nevadas, a value of 0.3 mm is suggested (Anderson 1973).

Table 6.9 lists snow accumulation and melt parameters used by SPUR. Initial values or suggested ranges from Anderson (1973) are included.

THE CHANNEL COMPONENT

The channel component routes water and sediment through the channel system. Limitations of the routing techniques can be found in Part I on the channel component by Lane.

On record 4, the basin-wide hydrograph parameters,

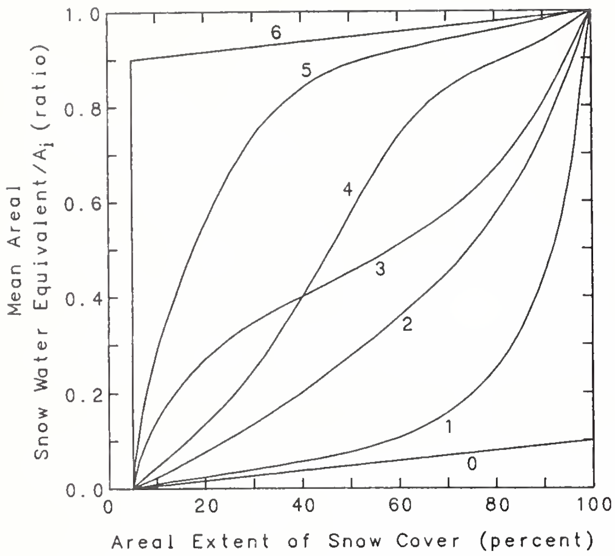

Figure 6.2
Snow cover areal-depletion-curve types corresponding to ADPT values of 0, 1, 2, 3, 4, 5, and 6 (modified from Anderson 1973).

Table 6.9
List of parameters and suggested value or range for HYDRO-17 snow accumulation and melt routines used in SPUR

Parameter	Value
SCF	1.0 - ? (1.2)[1/]
MFMAX	See table 6.8
MFMIN	See table 6.8
UADJ	0.03 - 0.19 mm/mb
SI	
ADPT	
NMF	0.15 mm/°C/6-h
TIPM	0.1 < TIPM < 1.0 (0.5)
MBASE	0.0 °C
PXTEMP	0.0 - 2.0 °C
PLWHC	0.02 - 0.05
DAYGM	0.0 - 0.3 mm

[1/] Value in parentheses is suggested.

Source.--Anderson (1973).

C1 through C5, are entered which predict peak flow response. Parameters C1 and C2 relate drainage area to mean event flow duration, and parameters C3 and C4 are for the watershed area to event runoff-volume equation. Parameter C5 is the hydrograph-shape parameter. The relationships and parameter values listed in table 6.10 were derived from an analysis of small watershed data in Arizona. Streamflow from these basins was ephemeral or intermittent so these relationships should not be applied to perennial streams. For watersheds with a significant baseflow component, a steady state procedure is used to determine daily flow rate. When a rainfall event occurs, the routing routines using the double-triangle approximation are used, thus the baseflow is neglected in this case.

Values for hydrograph parameters for the Arizona watersheds from Murphey et al. (1977) are given in table 6.10. The preferred method of deriving parameter values is using data from a gauged watershed in the region of interest and obtaining parameters using the established equations. Extrapolation of the derived parameters to the simulation watershed should take into account relationships such as area, elevation, length, and soils to the watershed from which the parameters were derived.

The coefficient, C1, in the runoff-duration/watershed-area relationship was between 2.0 and 5.5, inclusive (table 6.10).

The exponent in the runoff-duration/watershed-area relationship, C2 on record 4, ranges between 0.2 and 0.5, inclusive (Table 6.10). If hydrograph analyses cannot be conducted, the recommended value for C2 is in the range of 0.2 to 0.3.

The parameter C3 on record 4 is the coefficient in the runoff volume/watershed-area relationship, and values for C3 are listed in table 6.10.

The exponent in the runoff-volume/watershed-area equation, C4 on record 4, lies between 0.0 and 0.2, but a value in the interval 0.1 to 0.2 is suggested after C3 has been selected.

The hydrograph-shape parameter, C5 on record 4, can be found by relating the mean peak flow rate to the mean runoff volume divided by the mean storm duration. Estimates are found in table 6.10.

The channel hydraulic conductivity is used to calculate channel transmission losses. Table 6.11 is a list of effective hydraulic conductivity values for different types of material and can be used as a guide for streams where it is known that channel transmission losses are important.

The hydraulic properties of the channel are calculated with the Manning equation. Channels are assumed to be rectangular in cross section. On record 6, Manning's "n" values are required for both total (XN) and wall (XNW) roughness. Table 6.12 lists values for total roughness for various types of open channels. The relationship between XN and XNW can be seen in table 6.13. The reader is referred to the channel component documentation by Lane (Part I, Chapter 5) for a more complete description of the relationship between total and wall roughness.

The sediment transport routines estimate both suspended load and bed load. All material is assumed to be present in the bed and only transport capacity limits sediment yield.

Table 6.10
Parameters in the transmission loss, streamflow routing procedures

Parameter or variable	Range in values	Source of estimate and comments
Watershed area A	---	Topographic map. Drainage area contributing to the channel segment.
Channel Length x Width w	---	Topographic map and field observations.
Hydraulic conductivity K	0.001 - 5.0	Table 6.2 or runoff data. Function of channel alluvium, antecedent moisture, and so forth.
Hydrograph parameters		
C1	2.0 - 5.5	Murphey et al. (1977) or hydrograph analysis.
C2	0.2 semiarid to 0.5 subhumid.	Murphey et al. (1977) or hydrograph analysis.
C3	0.03 - 0.07 semiarid.	Murphey et al. (1977) or hydrograph analysis.
C4	-0.2 semiarid to 0.0 subhumid.	Murphey et al. (1977) or hydrograph analysis.
C5	2.8 - 6.0	Murphey et al. (1977), SCS (1972) or hydrograph analysis.
D	> 0.0	D = C1 A C2, mean duration of flow (h)
V	> 0.0	V = C3 A C4, mean runoff volume (in), must convert to acre-ft.

Particles less than 0.062 mm in diameter compose the silt-clay fraction and are transported as suspended load. The decimal value of the bed material in this category is the fraction of silt and clay (FSC) on record 6. Table 6.14 shows an upper limit of 0.10 for FSC. The sediment transport routines have not been tested for values greater than this, as these larger values may represent a channel with more cohesive material. The suspended sediment transport parameter, CAS on record 6, is also listed in table 6.14 with suggested values.

The bed-load calculations require a distribution of particle sizes for the material greater than 0.062 mm in diameter and the number of particle-size classes (NPC) is entered on record 6. The maximum allowed number of classes is 10. The median particle diameter for a class (DI) and the fraction of material represented by that diameter (FI) are entered on records 7 and 8, respectively. The sum of the FI values must equal 1.0 minus FSC (table 6.14). The median particle diameter of the bed material, d_{50} on record 6, must be within the range given in table 6.14.

Ponds are simulated as part of the channel system. A channel ends at a pond, or its outflow is inflow to a pond, and outflow from a pond is into another channel segment (figure 3.2). The inputs for ponds are on record 9 and they are self-explanatory. Most of them will require a field survey. The hydraulic conductivity for seepage out of the pond bottom can be obtained from Table 6.11.

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Table 6.11
Effective hydraulic conductivity for transmission losses in channel alluvium[1]

Bed material group	Bed material characteristics	Effective hydraulic conductivity[2] (in/h)
Very high loss rate	Very clean gravel and large sand $d_{50} > 2$ mm.	> 5.0
High loss rate	Clean sand and gravel under field conditions. $d_{50} > 2$ mm.	2.0 - 5.0
Moderately high loss rate	Sand and gravel mixture with less than a few percent silt-clay.	1.0 - 3.0
Moderate loss rate	Mixture of sand and gravel with significant amounts of silt-clay.	0.25 - 1.0
Very low loss rate	Consolidated bed material with high silt-clay content.	0.001 - 0.1

1/ Based on analysis of data from 14 channel reaches in Arizona, Texas, Kansas, and Nebraska, data from 14 other channel reaches in Arizona, and canal seepage rates in unlined canals.

2/ Values of effective hydraulic conductivity reflect the flashy, sediment-laden character of many ephemeral streams, and thus, do not represent clear-water infiltration rates at steady state.

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Table 6.12
Approximate hydraulic roughness coefficients for open-channel flow. Values are for the total roughness coefficient, n_T

Total Manning's n value n_T	Description of channel
(0.02 - 0.10)	Excavated or dredged channels[1/]
0.022	Earth, straight, uniform, and clean.
0.027	Same, but with some short grass or weeds.
0.025	Earth, winding, and sluggish with no vegetation.
0.030	Same, but with some grass or weeds.
0.080	Channels not maintained; weeds and some brush.
(0.03 - 0.10)	Natural streams[1/]
0.030	Clean and straight; no rifts or deep pools.
0.040	Clean and winding; some pools and shoals.
0.048	Clean and winding; some weeds, stones, and pools.
0.070	Sluggish reaches with weeds and deep pools.
(0.012 - 0.040)	Wide alluvial channels[2/]
0.018 - 0.030	Ripples bed form, sediments finer than 0.6 mm, Froude Nos. < 0.37.
0.020 - 0.040	Dunes bed form, Froude Nos. 0.28 to 0.65.
0.014 - 0.030	Transitional bed form, Froude Nos. 0.55 to 0.92.
0.012 - 0.030	Antidunes bed form, Froude Nos. > 1.0.

1/ Source.--Chow 1959.

2/ Source.-- ASCE 1969 and Simons and Richardson 1971.

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Table 6.13
Approximate hydraulic roughness coefficients for total and bank or wall roughness in natural, alluvial channels

Description of channel	Total n_T	Wall n_w
Upland streams		
Sand and gravel bed; bare, exposed banks	0.030 - 0.040	0.030 - 0.045
Sand and gravel bed; exposed banks with vegetation; grass and weeds.	0.035 - 0.045	0.035 - 0.050
Sand and gravel bed, vegetated banks; grass and weeds, with some brush.	0.040 - 0.048	0.045 - 0.060
Wide, alluvial channels		
Sand bed; bare, exposed banks	0.025 - 0.035	0.030 - 0.040
Sand bed, vegetated banks	0.030 - 0.040	0.035 - 0.050
Gravel bed, vegetated banks	0.030 - 0.040	0.035 - 0.050

Note.--See table 3.12 for values of n_T. In natural alluvial channels, n_w is usually greater than n_T.

Table 6.14
Parameters in the sediment transport, sediment yield procedure

Parameter or variable	Range in values	Source of estimate and comments
Channel		
Width w	> 0.0	Cross-section data. This width is not the mean reach width as used in the transmission loss equations; it is the actual width at the cross section of interest.
Slope s	> 0.0	Topographic map; field observations.
Sediment		
Particle-sized distribution (f_i, d_i)	$f_i = 1 - f_{sc}$	Bed material samples. Distribution of bed sediments larger than 0.062 mm. Up to 10 size fractions.
d_{50}	$0.062 < d_{50} < 2.0$ mm	Bed material samples. Median particle size.
f_{sc}	$0.0 < f_{sc} < 0.10$	Bed material samples. Proportion of bed material finer than 0.062 mm. Values of $f_{sc} > 0.10$ may indicate cohesive material.
Hydraulics		
Total roughness n_T	0.012 - 0.048	Tables 3.12 and 3.13; field observations.
Wall roughness R_w	$0.030 - 0.060^+$	Table 3.13; field observations.
Transport parameters		
$B_s(d_i)$	> 0.0	Equation 55 of chapter 5, Part I.
$B_c(d_i)$	> 0.0028	Equation 56 of chapter 5, Part I.
CAS	1.0 - 10.0	Suspended-transport parameter. Complex function of particle dynamics. Estimate from calibration using observed data. Default value, corresponding to medium-sized silt, of CAS = 5.0 is recommended in the absence of better estimates.

7. ANIMAL-COMPONENT PARAMETER ESTIMATION

J.W. Skiles, M.D. MacNeil, L.A. Torell

INTRODUCTION

Three types of information are needed to initialize and use the animal component of the SPUR model: (1) timing of grazing and diet supplementation; (2) growth and weight information; and (3) preferences for forage and location. We assume that the experimenter knows the system he or she wishes to simulate well enough that the Julian days for beginning and ending grazing of domestic animals and wildlife species need not be supplied in this User Guide. Further, it is assumed that the user knows when he wishes to supplement steer diets, the amount of supplement to be used, and the digestibility of the supplement.

GROWTH AND WEIGHT INFORMATION

Weight information for the grazing steer must be supplied by the user. The variables are age, in Julian days, at turnout (TAVG), weight, in kilograms, at turnout (W) and the asymptotic weight, in kilograms, of the particular steer breed being used in the simulation (WMA). Table 7.1 provides weight information according to steer breed. The lower 400-day weight indicated for each type of cattle is an estimate for cattle in average condition. The upper 400-day weights and the average daily increments are from the Germ Plasm Evaluation Program conducted at the U.S. Meat Animal Research Center, Clay Center, Nebraska. The daily increment is similar for all types of cattle except those with low growth potential due to assumed energetic limitations of growth imposed by feeding a diet high in roughage from weaning to turnout. Cattle that are moderate or above in growth potential are genetically capable of weight gains greater than those indicated in table 7.1.

To calculate the weight at turnout (W), use the expression:

$$W = 400\text{-day weight} + [(\text{age at turnout} - 400)\ \text{average daily increment}] \qquad (1)$$

For example, for a Brahman steer aged 365 days at turnout, the 400-day weight should be decremented by 22.75 kilograms.

The user, not using values in table 7.1, should provide realistic weight information and should refer to the chapters on error checking by the SPUR codes and the discussion of error 29 for the field-scale version of SPUR (chapter 8) or error 79 for the basin-scale version of SPUR (chapter 9).

The amount of forage consumed daily by the grazing steer is not specified by the user. Rather, it is calculated from the age and weight of an average steer at turnout and the asymptotic weight of the steer variety. This is not the case with the wildlife species. Wildlife are not grown in the SPUR model. They act as a sink for the forage classes of live and dead phytomass for each forage species. Consequently, the user supplies the number in each wildlife species (herd) and the amount of forage consumed daily by one member of that species. The model then apportions the forage intake according to the user-supplied wildlife preferences for forage and location.

ANIMAL PREFERENCES

A unique feature of the SPUR animal component is the allowance made for selection of site and forage preferences by the simulated herbivores. The preferences are supplied by the user and are used to determine where the animals graze and how much of which forage class (live or dead) is harvested. In specifying the site preferences of the grazing animals, the user may wish to consider abiotic factors that influence site preference and are discussed in the following section. They are number and amount of plant species, temperature, wind, topography, type of soil, or availability of salt. (The following discussion is modified from Skiles (1984).)

Preference for Site

The number and amount of plant species available as forage to a given herbivore species is certainly dependent on the site that herbivore inhabits. For example, if the animal is essentially a grass grazer, one would not expect it to forage in heavy shrub cover or in dense forests. Other abiotic requirements for herbivore habitats are rather obvious. The large herbivores considered herein are warm-blooded. This means that the ambient temperatures to which they are exposed must be within the range of temperatures over which a homeothermic organism can survive. Temperature can affect grazing behavior and the amounts foraged. For cows, Smoliak and Peters (1955) found that in winter, temperature was the most important factor controlling grazing time and frequency. Temperature regulation, either active (moving into shade) or passive (growing a winter coat) can result in a change of site and consequently diet composition.

Water availability is also important and obvious in site selection. It is needed to flush out excess salt in herbivore blood streams. Wagnon (1965) estimated that 5 gallons of urine were necessary to eliminate one pound of salt. During periods of high temperatures and dry forage, cattle may require as much as 20 gallons of water per head per day (Riggs et al. 1953). Thus, distance to water is important.

Such high water requirements do not always hold for other herbivores, however. Deer, for example, are known to be capable of attaining their moisture requirement from snow or succulent plants. During hot summer days, however, they probably do require drinking water (Cowan 1956).

Aside from natural ponds, springs, and streams,

Table 7.1
Average domestic-animal 400-day weights, average daily weight increments, and asymptotic weights by type of cow and by crosses

Type of cattle	Predominant breeding of example crosses	400-day weight (kg)	Daily increment (kg)	WMA (kg)
Small, relatively low growth potential	Jersey Longhorn	260 - 293	0.48	452
Small to moderate size and growth potential	Hereford Angus	284 - 316	.64	509
Moderate size and growth potential	Limousin Tarentaise	297 - 312	.65	542
Moderate to large size and growth potential	Gelbvieh Brahman	303 - 336	.65	558
Large size, high growth potential	Simmental Charolais	315 - 334	.64	585

water availability can change with changing seasons and during periods of drought. Available water is influenced too by the seasonal movement of animals into or out of an area.

Wind is also a factor in determining site use. On windy days deer have been observed to change bed sites several times to shelter from the wind (Bailey 1960). Since deer feed near their beds in the early morning, such movement can alter an animal's feeding site.

Topography is another consideration. Deer are known to seek bed sites with a view of the slope below. Deer also prefer hillsides to flat areas while grazing and they appear to like to feed with their front feet higher than their back feet (Cowan 1945). This can result in heavy usage of hillside areas.

Soil type can influence site selection. Some herbivores avoid sites with clay soils after heavy rain but use those sites when the soil is dry (Van Dyne, personal communication).

Though water is necessary to remove salt from herbivore blood streams, salt is necessary for some metabolic processes. Salt, then, is an abiotic factor influencing site selection. Depending on the location of salt licks, animals can be attracted to graze in desired areas (Johnson 1979). Other considerations include presence or absence of shade, trails for movement between sites, and concentration (for whatever reason) of insects. All these could be used in the assignment of animal preferences for site.

Preference for Forage

A further unique feature of the SPUR model is the setting by the user of the herbivore preferences for specific forage species, the live and standing dead thereof. Diet preference has been measured in many studies for a number of large herbivores. In the absence of actual preference data, the user may wish to consider the information presented in the following review as an aid in establishing forage preferences. He or she may also wish to consult the specific references cited.

Considered conceptually, diet selection (for example, preference) is related to variables that Ellis et al. (1976) call secondary control variables. These include the body size and metabolic body weight. These two variables dictate the energy requirements of the animal and can be modified by physiological state (such as resting or running) and reproductive state (such as pregnant or lactating). Ellis et al. (1976) likewise consider that ambient temperature modifies energy requirements. They also contend that there is a minimal or threshold amount of energy required for a consumer to maintain or increase its energy or nutrient balance called the Consumer Food Requirement or CFR. The last is dependent on the food quality (FQ) available, meaning the CFR will be met earlier in the grazing period if the food available is high in the requisite diet currency than if not. (Currency is used here to label the quantity of some requirement for which the herbivore forages. Usually this currency is energy stored in plant tissues (Emlen 1966, Pyke et al. 1977, Schoener 1971), but may also be

minerals, nutrients and plant proteins, and, during the dry season or in arid areas, water.) Thus, CFR is a function of ambient temperature (T), metabolic rate (MR), body size (W), physiological state (PS), and reproductive state (RS) as well as the quality of available food. For herbivore j feeding on plant species (or plant group) i:

$$CFR_j = f(MR_j, W_j, T, PS_j, RS_j, FQ_i) \qquad (2)$$

Given the relationship above, preference, defined as D, must be tailored to satisfy the CFR. Visual cues, such as size and shape, color, and presence or absence of thorns and inflorescences also contribute to forage selection. The relative abundance of a food vis-a-vis other foods (or novelty as Ellis et al. (1976) regard it) is a factor in selection. Thus, preference (D) of herbivore j for plant (group) i is a function of forage size (FS), forage novelty (FN), and temperature (and perhaps humidity (H) which affects plant tissue turgor and hence taste, appearance, and so forth). Or:

$$D_{i,j} = f(FS_i, FQ_i, FN_i, RS_j, PS_j, T, H) \qquad (3)$$

These forage properties (size and shape, novelty, and quality) cause either ingestion or rejection by the herbivore; they are detectable before ingestion. Other properties are detectable after digestion, and if unfavorable, preclude further ingestion of that forage item. These two properties are called sensory and nutritional properties, respectively (Westoby 1974). The nutritional property which concerns plant consitutents requires further discussion.

A herbivore may have essentially three mutually exclusive responses to characteristics of a forage plant once it is ingested: (1) a positive response, meaning the animal considers the plants palatable; (2) a negative response, meaning the animal avoids the plant; and (3) a neutral response which implies the animal neither seeks out nor avoids a forage plant. The literature gives a number of examples of specific plant substances that can cause these responses.

The following (partially from Marten (1969) and Westoby (1974)) found that sugars and soluble carbohydrates elicit a neutral response from large herbivores: Warmke et al. (1952), Hardison et al. (1954), Reid and Jung (1965), Reid et al. (1966), O'Donovan et al. (1967), Buckner et al. (1969), Rabas et al. (1969), and Marten and Donker (1964). The following workers, however, found positive responses to the same substances: Cowlishaw and Alder (1960), Gangstad (1964), Bland and Dent (1962, 1964), Dent and Aldrich (1963), Heady (1964), and Reid et al. (1967).

A neutral response to protein content was found by Archibald et al. (1943), Reid and Jung (1965), Reid et al. (1966), Reid et al. (1967), Buckner et al. (1969), and O'Donovan (1967), while protein content caused a positive response in work done by Hardison et al. (1954), Cook (1959), Blaser et al. (1960), Burton et al. (1964), Gangstad (1964), Heady (1964), and Fontenot and Blaser (1965).

Leigh (1961), Reid et al. (1966), Reid et al. (1967), Archibald et al. (1943), Buckner (1955), and Hardison et al. (1954) found a neutral response to crude fiber, acid detergent, or cell wall structure. Blaser et al. (1960), Gangstad (1964), Arnold (1964), Heady (1964), and Fontenot and Blaser (1965) established that those substances produced a negative response in large herbivores.

Martin and Donker (1964) and Reid and Jung (1965) contend that mineral content produces a neutral response while Beaumont et al. (1933), Hardison et al. (1954), Ivins (1955), Cook (1959), Gangstad (1964), and Cowlishaw and Alder (1964) say that mineral content produces a positive response.

Other substances affect the animals' response to ingestion. Cook (1959) reported that sheep respond negatively to cellulose concentration. Hardison et al. (1954) and Reid and Jung (1965) reported no particular response to various vitamin contents of foods. Buckner (1955) found a netural response and Archibald et al. (1943) found a positive response to carotene concentrations in plants.

A hypothesis presented by Caswell et al. (1973) (who consider primarily only insects) is that herbivores that have evolved in temperate climates tend to avoid plants with the C_4 dicarboxylic acid pathway of carbon fixation. (Heidorn and Joern (1984) confirm this hypothesis for grasshoppers.) Presumably this avoidance is due to location and starch-storing functions of chloroplasts in C_4 species and to phloem and bundle sheath concentrations and location. Evans and Tisdale (1972) documented the preference of cattle, sheep, and mule deer for the C_3 species Agropyron spicatum over the C_4 species Aristida longiseta. Though they did not specifically study carbon fixation pathways, their evidence supports the hypothesis of Caswell et al. (1973).

The herbivore responses to plant substances are summarized in table 7.2.

Obviously, preference is not a simple consideration. Preference or selectivity or electivity (Ivlev 1961, Jacobs 1974) is, as a consequence, difficult to accurately define. Stoddard et al. (1975) define preference as the selection of plants by animals. They contend that the term is often used incorrectly when "palatability" is meant. Palatability, they say, refers to the attractiveness of a forage, not its actual selection. This attractiveness is related to preingestion cues, such as taste, odor, texture of the plant, and other visual stimuli (Westoby 1974). The contrast between preference and palatability is further discussed by Heady (1964) and Van Dyne et al. (1980).

Subjective Measures of Forage Preference

Examples from the literature follow in which preference is measured largely on a subjective basis. These measures of preference have their value in resource management although they may not be particularly elegant.

Table 7.2
Plant substances that are reported to cause various responses in grazing herbivores

Plant substances	Response and reference: Neutral	Positive	Negative
Sugars and soluble carbohydrates.	Warmke et al. (1952); Hardison et al. (1954); Marten and Donker (1964); Reid and Jung (1965); Reid et al. (1966); O'Donovan et al. (1967); Buckner et al. (1969); Rabas et al. (1969).	Cowlishaw and Alder (1960); Gangstad (1964); Bland and Dent (1962, 1964); Dent and Aldrich (1963); Heady (1964); Reid et al. (1967).	
Protein content.	Archibald et al. (1943); Reid and Jung (1965); Reid et al. (1967); Buckner (1969); O'Donovan (1967)	Hardison et al. (1954); Cook (1959); Blaser et al. (1960); Burton et al. (1964); Gangstad (1964); Heady (1964); Fontenot and Blaser (1965).	
Crude fiber, acid detergent fiber, cell wall structure.	Leigh (1961); Reid et al. (1966); Reid et al. (1967); Archibald et al. (1943); Buckner (1955); Hardison et al. (1954).		Blaser et al. (1960); Gangstad (1964); Arnold (1964); Heady (1964); Foutenot and Blaser (1965).
Mineral content.	Martin and Donker (1964) Reid and Jung (1965).	Beaumont et al. (1933); Hardison et al. (1954); Ivins (1955); Cook (1959); Gangstad (1964); Colishaw and Alder (1964).	
Cellulose concentration.			Cook (1959).
Vitamin content.	Hardison et al. (1954); Reid and Jung (1965).		
Carotene concentration.	Buckner (1955).	Archibald et al. (1943).	
C_4 photosynthesis.			Caswell et al. (1973); Heidorn and Joern (1984).

The following summary is from 19 papers in which preference was determined.

(1) Percent time grazing -- Smith and Hubbard (1954) offered browse species to tame deer in feeding trials. They ranked the forage species according to time spent by the deer browsing and according to the weight of forage consumed. The ranking was labeled preference. Stormer and Bauer (1980) considered the time spent by tame deer in various forest stands of differing plant species composition a measure of habitat preference. Healy (1971) established high, medium, and low preference ratings for tame deer fed clipped forage. The ratings were determined by comparing the percent of time a deer spent eating a plant species with the percent of that plant species' weight in the sample.

(2) Percent grazed plants -- Crouch (1966), working with black-tailed deer, simply counted leaves and twigs browsed in sample plots to get a cumulative percent of the available forage plants browsed. This was termed preference. The study by Hurd and Pond (1958) measured utilization of forage species as percent weight removed in sample plots. Preference ratings were derived from these utilization estimates. Herbel and Nelson (1966) tested for preference differences between Hereford and Santa Gertrudis cattle on New Mexico ranges. Their measure of preference was the percent of the total of all observations that a species of forage

plant was grazed. Dwyer et al. (1964) considered percent of plants grazed as an index to forage preference in their study of steer preferences.

(3) Animal presence or density -- Reardon et al. (1978) consider the density of deer on various rangelands grazed by livestock on a deferred rotational basis. They contend that the number of deer present on different rangelands indicate a species preference for that grazing system. Coleman et al. (1971) consider that selective grazing by herbivores, in this instance cattle, constitutes preference. They correlated preference to chemical constituents of the forage plants. Miller (1968) considered preference as the ratio between the percent of deer of the total deer sighted in each plant community and the frequency of occurrence of the plant community.

(4) Plant use -- Beale and Smith (1970) studied pronghorn antelope in western Utah. By using some rumen samples and random observations of feeding sites and occular estimates of use on sample plots, they determined utilization of forage species. By ranking the utilization figures from low to high, they established a preference rank. Korschgen et al. (1980) considered utilization the same as preference as long as deer populations remained within the carrying capacity of the land. Severson and May (1967) also consider utilization synonymous with preference, but their study dealt with antelope and domestic sheep. For their study of deer and cattle, Drawe and Box (1968) obtained preference values simply by multiplying percent frequency of a forage plant on the range by the percent utilization.

(5) Simple mathematical relationship -- Heady and Torell (1959) sampled the botanical composition of study plots and the extrusa of esophageally fistulated sheep. The contribution in percent of the diet compared with the percent contribution to the grassland of a particular forage species constituted preference. McCaffery et al. (1974) determined preference by multiplying the percent volume of a plant species in the diet determined from rumen extrusa analysis by the percent occurence of the plant species in the diet (that is, frequency). Bedell (1968) used the difference between forage percent in the diet of cattle and sheep and the forage on the rangeland, the last being determined from clipped plots, the first from fistulated animals.

(6) Other measures -- Longhurst et al. (1979) offered forage to caged animals in feeding trials. Based on the selective feeding of the sheep and deer used in the study, they established a preference rank of preferred forage species. Their intent was to determine palatability of the browse species in the study area. (Note here that the word palatability may be used improperly.) In eastern Colorado, Reppert (1960) dealt with forage preferences in cattle. His observations of grazing heifers were based on mouthfuls of forage. He determined preference by the percent composition each forage plant species contributed to the total forage consumed.

These papers and the procedures for preference determinations explained in them lack a certain rigor in those preference determinations. The next section discusses examples of preference determination which involve somewhat more manipulation of the data.

Examples of Calculated Preference Values

Other workers use some means or methods to establish preference values or ranks of forage species in herbivore diets. These studies do not necessarily calculate preference using an index, but some relationship between forage plants and animal preference is established. These methods include:

(1) Availability or availability factors -- Drawe (1968) and Everitt and Drawe (1974) used an availability factor in their determination of preference. The factor was arbitrarily set at 1 for rare, 2 for occasional, 3 for frequent, and 4 for abundant occurrence of a forage plant on the range. The factor was then divided into the product of the percent frequency of occurrence and the percent volume of the forage plant in the diet. Chamrad and Box (1968) sampled the range of south Texas and took rumen samples from white-tailed deer. Their preference value was calculated by multiplying percent frequency of a forage plant in a rumen sample times the percent volume of the plant in the rumen sample. The preference rating they used took the preference value and divided it by an availability factor determined from range sampling. Krausman (1978), in his determination of preference for mule deer and white-tailed deer in Texas, first calculated an availability number by multiplying the frequency times the percent density of the plant in the field. The range on this value was zero to 10,000. Preference was then calculated as percent frequency times the percent volume in the rumen divided by availability.

(2) Forage weight in the community -- The percent contribution of each forage species in the diet divided by the percent by weight of that species in the community was the method whereby Collins et al. (1978) determined preference for forage by elk. This same method was used by Deschamp et al. (1979).

(3) Relative preference index -- Krueger et al. (1974) used a relative preference index to measure preference in sheep as related to taste, touch, smell, and sight of forage plants. Uresk and Rickard (1976) used the same relative preference index for their study of steer diets in south-central Washington.

(4) Site use -- Stevens (1966) recorded instances of use of forage species, one instance being one bite, of cattle, sheep, and elk. Preference was established as seasonal or vegetation type use as an average of aggregate percent use per site divided by percent of sites on which an item was used in relation to all sites in that category. Martinka (1968, 1969) used an aggregate-percentage method to determine preference of white-tailed deer, mule deer, and elk. In the 1968 paper, rumen analysis indicated diet botanical compo-

sition. In the 1969 paper, feeding sites were examined for instances of use of plant species. The preference index was then calculated as the average percent use of all plants used per site divided by the percent of sites (within a plant community) in which a specific taxon was used.

(5) Averages -- Marcum (1979) studied the food habits of a Montana elk herd in the summer and fall. His preference values were derived from dividing average relative plant utilization for each plant species by the average absolute cover of the species for all study plots measured during a given month. Smith (1953) studied captive mule deer and fed them selected forage from that available in the study area. Over a total of seven trials and a period of five months, he established preference values for some 32 forage plants by dividing the average consumption of any species during a period by the average daily forage intake during the corresponding period. Lay (1967), studying deer range in eastern Texas, measured utilization of growth on sample plots. These measures were then used to determine palatability ratings. A "utilization mean" was then derived by dividing the percent utilization readings by the number of plots in which they occurred. The means were then combined into a mean index for each group or forage class (such as browse, pine, or grasses).

(6) Statistical tests -- Clary and Pearson (1969) studied cattle preferences for forage species in northern Arizona. Their measure of preference compared actual forage species use to a base or standard species. They tested for significant differences between the two with covariance analysis. Tomanek et al. (1958) used a chi-square test to determine if cattle were grazing any of six mixed prairie grasses in other than random fashion. They correlated results of this test with percent occurrence of species on each site, percent of grazed samples on each site, and the number of times a species was grazed in relation to the number of times that species was present on a transect. From these observations they established three classes of preference: significant negative preference, significant positive preference, and no significant preference.

(7) Other methods -- Oldemeyer et al. (1971) examined feeding sites to determine relative frequency of grazing. They then calculated an index of preference by dividing the percent of a species to be grazed or browsed by its percent plant cover.

The SPUR user may be faced with using preference values presented in the literature. He or she may also have raw data from which preference values may be calculated. The following discussion is intended to help the user in assigning the preference vectors necessary for the simulated grazing steers and/or wildlife species.

This brief survey of the literature on forage preference by large herbivores yields the conclusion that many studies of forage intake rate or botanical composition of the diet attempt to account for and often measure forage preference. But, the SPUR user is now faced with the prospect of trying to fit preference data into some sort of vector which will sum to 1.0 and reflect the preference of the animal species being simulated. With that objective in mind, four preference measures or indices are compared below with calculations being done on a common data set. Two measures are appropriate for use in calculating the forage preference vector for the SPUR model. The data set is from a northeastern Colorado, shortgrass prairie rangeland and is reported in Van Dyne (1981). The light-grazing data regime is used, data for which are reported in table 7.3.

Table 7.3
Herbage and diet botanical composition by percent dry weight of 4 herbivores

Herbage and animal species	Composition of diet: Grasses	Forbs	Shrubs
Herbage	75	10	15
Cattle	93	8	<1
Bison	70	29	1
Sheep	41	52	3
Pronghorn antelope	13	87	<1

Source.--Van Dyne (1981).

The data are for four herbivores: Cattle, bison, sheep, and pronghorn antelope and are presented according to forage class, that is, grasses, forbs, and shrubs. These classes could also be the green vegetation and standing dead vegetation simulated in the SPUR model. Cattle, in this study, consume primarily grass (93 percent), some forbs (8 percent) and almost no shrubs (<1 percent). Bison consume 70 percent grass, almost 30 percent forbs and very little of shrubs (1 percent). Sheep on the Pawnee Site in eastern Colorado consume 41 percent grass, 3 percent shrubs, and had the major part of their diet derived from forbs (52 percent). Approximately 4 percent of the sheep's diet was made up of other plants. Pronghorn antelope ate less than 1 percent shrubs, some grass (13 percent), and consumed 87 percent forbs.

The first index R1 is called here the simple ratio and is the amount of a forage (F) of a particular class (or species) i in the diet divided by the amount of herbage (H) of a particular class (or species) i found on the range. It is similar to the index developed by Van Dyne and Heady (1965) and analogous to the measure of Edmondson and Winberg (1971). Thus, the simple ratio (SR) for a forage class i is:

$$R1_i = SR_i = \frac{F_i + 0.01}{H_i + 0.01} \qquad (4)$$

(The addition of the term 0.01 ensures that no

division by zero will occur should the H_i be zero because the range survey failed to find any of a particular rare class of plant or plant species on the range.)

The second preference calculation (R2) normalizes the simple ratio so that when summed over i (all forage classes), the result is unity. The expression is:

$$R2_i = \frac{SR_i}{\sum_i SR_i} \qquad (5)$$

The third method of preference calculation (R3) utilizes the so-called arithmetic ratio of herbage to forage. This is also Ivlev's (1961) electivity index. It requires subtracting the herbage on the range from the forage in the diet for each class and dividing the difference by the sum of the forage in the diet and the herbage on the range for each forage class. The expression is:

$$R3_i = \frac{F_i - H_i}{F_i + H_i} \qquad (6)$$

As may be seen, the arithmetic ratio, R3, yields values in the range of -1 to 1 inclusive. Using equation 6, a value for R3 of 1.0 is interpreted as 100 percent selection for a plant or plant group; a value of 0.0 is selection neither for nor against a plant group; a -1.0 is 100 percent rejection of a plant or a plant group.

The fourth method of forage preference calculation might be to normalize the values of R3. Recall, however, that the SPUR animal component requires the forage preference vector for each herbivore species to sum to 1.0. To put the values derived from equation 5 into the requisite range, 1.0 is added to each $R3_i$ value, and the resultant value is normalized. The sum, then, of all the preference values for one herbivore species is unity. The expression is:

$$R4_i = \frac{R3_i + 1}{R3_i + n} \qquad (7)$$

The addition of n, the number of forage species, to the denominator ensures that the calculation of R4 is simultaneous, taking into account all forage species.

The results of these four calculations are shown in table 7.4.

The results of the calculations essentially show the trend of the raw data shown in table 7.3. That is, cattle have the highest preference of all the herbivores for grasses. Bison show the second-highest preference for grasses, with sheep and pronghorn antelope following, in that order. Pronghorn antelope show the highest preference for forbs, as would be expected from the raw data, followed by sheep, bison, and cattle for that forage class.

The calculation of preference using the arithmetic ratio yields what appear to be puzzling results. Cattle, for example, chose a diet composed of 93 percent grasses, yet the arithmetic ratio produces a cattle preference for grasses of 0.11. That value seems rather low in view of the raw data. The matter is explained however when one considers that the arithmetic ratio calculates preference simultaneously for all forage and herbage classes. A preference value calculated by this method then must be evaluated in relation to all other preference values for a particular herbivore species. Viewed in this context, the seemingly low cattle preference for grasses is, indeed, rather large when compared with cattle preference for shrubs. The values shown under the normalized arithmetic-ratio heading, scaled between 0.0 and 1.0, show the same tendencies as do those values in the previous column.

For the SPUR user with numerical animal preference data, the normalized simple ratio, equation 4, or the normalized arithmetic ratio, equation 6, may be used to calculate the forage preference vectors required by the SPUR model. The normalized arithmetic ratio, however, is recommended since it is based on the calcu- lation of preference which considers all forage classes simultaneously.

ECONOMICS

The information required for the economic analysis subcomponent of SPUR is (1) beef prices for various weight classes of steers, (2) an appropriate real rate of interest (actual interest rate minus inflation rate), and (3) fee and nonfee costs of harvesting forage. Using this information, SPUR calculates the net value of the livestock produced during each year of the simulation and discounts the income stream to net present value.

The beef prices as input reflect expected real prices. Normalized prices which eliminate short-term price fluctuations should be used. Alternatives include 3- to 5-year annual average prices, or prices derived by a normalization procedure (Niehaus 1978). Normalized prices for cattle are published each year by the Water Resource Council in Agricultural Price Standards. Purchase cost and gross revenue of steers are computed within the SPUR model based upon input beef prices and steer weight at turnout and roundup, respectively.

Since beef price reflects a real price, a real rate of discount (corrected for inflation) should also be used. Depending upon the expected rate of inflation, a discount rate between 4 and 8 percent will usually be appropriate.

Forage costs should include any costs incurred in grazing the forage, such as lease fees, labor, fuel, repairs, and supplies. Costs which vary with the level of production should be considered. and fixed expenses, excluded. As shown in the following tabulation, Torell (1984) estimated fee and nonfee costs to be about \$7.00 per steer per month for a public-land ranch.

Table 7.4
Comparison of preference values using four methods of calculation

Animal and forage class	Simple ratio	Normalized ratio	Arithmetic ratio	Normalized arithmetic ratio
Cattle				
Grasses	1.24	0.59	0.11	0.52
Forbs	.80	.38	-.11	.42
Shrubs	<.07	<.03	<-.88	<.06
Bison				
Grasses	.93	.24	-.03	.38
Forbs	2.90	.74	.49	.58
Shrubs	.07	.02	-.88	.05
Sheep				
Grasses	.55	.09	-.29	.26
Forbs	5.20	.87	.68	.62
Shrubs	.20	.03	-.67	.12
Pronghorn antelope				
Grasses	.17	.02	-.70	.13
Forbs	8.70	.97	.79	.81
Shrubs	<.07	<.01	<-.88	<.06

Summary of monthly costs

Ranch ownership expense	$ 3.19
Variable cost (VC)	2.00
General overhead (5 percent of VC)	.10
Interest on steers	2.05
Fee and nonfee costs per head per month	$ 7.34

Budgets published by the University of Nebraska Cooperative Extension Service (Jose et al. 1983) and the South Dakota Agricultural Experiment Station (Allen and Jibben 1977), which may more nearly reflect average costs on private lands, put the cost of forage for stocker operations in the $11 to $13 range. Thus, the interval $7 to $14 may reflect a representative range of costs. Effective use of public lands can reduce the cost of forage, the fees for Federal public-lands leases being somewhat lower than ranch ownership expenses.

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8. USING THE FIELD-SCALE VERSION TO CHECK FOR ERRORS IN INITIAL CONDITIONS

J.W. Skiles

INTRODUCTION

Aside from the errors which occur at compile time or execution time and which are machine, compiler, and often facility specific, the SPUR program can explicitly check for a number of error conditions in the input data. These conditions are brought about by input variables being out of the range of acceptable values or in some instances being equal to each other. However, the user may generate an error condition by including an extra input record, leaving out a specified input record, or having an input variable in an incorrect field. If the user does receive an error message and SPUR execution is terminated, he or she should first refer to table 8.1 and take the necessary action to remedy the error in the input file(s). If, from the record which holds the variable indicated, the user cannot discern the condition which generated the error, the record being read by SPUR should be checked against the record which corresponds to the variable being read. For example, if the user omits the parameters for a layer in the soil profile, the program will continue reading the numbers on the subsequent records, until all variables for the soil layers have been read. If the program then attempts to read the site and temperature elevations and the initial proportion of field capacity, but these have been read because of the postulated omission, the program will generate error condition 18 and halt execution. The error generated by the program is not because the initial field capacity is out of range; rather, it is because an improper number of records is present in the input file. The user must be sure each card specified for input is present in the input file.

If neither of these procedures removes the condition(s) which caused the generation of the error, the user should check that each variable is being read in the format fields specified in tables 2.3, 2.4, and 2.5. Typically, FORTRAN will cease execution if, for instance, two decimal points are read in the same field, or if a minus sign is read after a decimal point. The SPUR program will generate error messages even if none of these circumstances occur. As an example, suppose the user has two numbers on the same record to be read according to a format of 2F6.3. These numbers are 0.009 and 2.14. If the first number is too far to the right by one space, the first variable will be read as 0.00 and the second variable will be read (depending on the FORTRAN for the users' facility) as 92.14 or 902.14. The numbers may be correct, but the SPUR error-checking code will not know that these variables are in improper format fields and will generate the appropriate error message if the values are out of the programed range. The user must be sure that each variable read by SPUR is in the proper field.

The SPUR program, on recognizing an error condition, terminates execution immediately after writing an error message to the SUMARY file. That message has the form:

SPUR EXECUTION TERMINATION BY SPUR DUE TO
***** FATAL CONDITION n *****

where n is a positive integer and is the number of the error condition. The STOP statement in subprogram ERR also has the literal string FATAL ERROR which will be written to the output device in operation at the time of termination. This is machine and facility dependent and may be a LOG file, a DAYFILE, a batch listing, or a terminal.

EXPLANATION OF ERRORS

Though many of the error messages given in table 8.1 are self-explanatory, the user may still wish more information about some of them. For those users, the following short descriptions of the errors and the suggested action to rectify the condition(s) that generated them, follow.

Error 01. The program has read a value for the condition I curve number which is outside of the range 0.0 to 100.0, inclusive. This will cause the value of SMX in the subprogram FLDHYD to be of the wrong sign if CNI is less than 0.0 or it will cause SMX to be too small if the value exceeds 100.0. The result is that runoff for the site for which the illegal value was read will be incorrect. Adjust this value so that it is within the specified range.

Error 02. The program has read a negative value for the 15-bar soil water content for one of the soil layers at one of the sites. The units for this variable cancel (inches per inch). The initial soil-water calculation per layer per site requires the use of this variable as does the calculation for the 50-bar water content. Review the site description for the simulated site and reenter the value.

Error 03. The program has read a value for the 1/3-bar water content which is less than that of the 15-bar water content. The 1/3-bar water content is used in the same calculations as the 15-bar water content and is unitless. (See error 02 above.) Review the site description for the simulated site and reenter the value.

Error 04. The program has read a value for the soil porosity which is less than or equal to the 1/3-bar water content. The soil porosity is used in the same calculations as are the 1/3-bar and the 15-bar water content values and also in the calculation of the soil bulk density. It is unitless as well. Review the site description for the simulated site and reenter the value.

Error 05. The program has read a value for the saturated soil-conductivity which is negative. This parameter is used in the calculation of soil-water percolation and a negative value will cause an increase in soil water content of a soil layer rather than a decrease. Reenter the value.

Table 8.1
Error codes and the variables checked that cause the field-scale version of SPUR to terminate execution

Error codes	Variables checked	
01.	CNI	: the minimum curve number is not in the range of 0.0 to 100.0.
02.	SM15	: the 15-bar soil water content is not positive.
03.	SM3	: the 1/3-bar soil water content is not greater than the 15-bar soil water content.
04.	SMO	: the soil porosity is not greater than the 1/3-bar soil water content.
05.	SLSC	: the saturated-soil conductivity is not positive.
06.	SLDTH	: one of the soil-layer depths is not positive.
07.	GR	: the mulch (residue) cover factor is not in the range of 0.0 to 1.0.
08.	RD	: the rooting depth is negative.
09.	RD	: roots extend into lowest soil layer of one site.
10.	----	: NOT USED.
11.	----	: NOT USED.
12.	----	: NOT USED.
13.	CRIT	: $CRIT_{7,S}$ and $CRIT_{8,S}$ are equal in one plant species.
14.	TOPT	: the optimum temperature is less than minimum temperature for one plant species.
15.	TOPT	: the optimum temperature exceeds the maximum temperature for one plant species.
16.	AREA	: the totaled area for all the sites does not equal the area specified for the field.
17.	NSITE	: the number of sites is greater than 9 or less than zero.
18.	STF	: the fraction of field capacity is not in the range of 0.0 to 1.0.
19.	NWS	: the number of wildlife species is not in the range of zero to 10.
20.	TIN	: the day on which a wildlife species arrives on the field is less than 0.0.
21.	TOUT	: the day on which a wildlife species leaves the field is greater than 365.0.
22.	TIN-TOUT	: the day a wildlife species leaves the field is less than the day it arrives on the field.
23.	DMI	: the daily dry-matter intake for a wildlife species is less than or equal to 0.0.
24.	WMA	: the asymptotic weight of a cow is not in the range of 350.0 to 800.0.
25.	TINS	: the day on which steers are put on the field is less than 0.0.

Table 8.1--Continued
Error codes and the variables checked that cause the field-scale version of SPUR to terminate execution

Error codes	Variables checked	
26.	TOUTS	: the day steers are removed from the field is greater than year end.
27.	TINS-TOUTS	: the day on which steers are removed from the field is less than or equal to the day on which steers are put on the field.
28.	TAVG	: the initial age for the steers is not positive.
29.	WT	: the specified average steer weight will not fit the programed growth curve.
30.	DIGS	: steer diet supplement digestibility is not in the range of 0.5 to 0.9.
31.	TS1	: diet supplementing begins before the steers are put on the field.
32.	TS2	: diet supplementing continues after steers are removed from the field.
33.	MFMAX	: the maximum-melt factor is less than the minimum-melt factor or 0.0.
34.	MFMIN	: the minimum-melt factor is less than 0.0.
35.	TIPM	: the weight for antecedent temperature for snow heat content is not in the range of 0.0 to 1.0, inclusive.
36.	PLWHC	: value is outside of the range of 0.0 to 0.99, inclusive.
37.	SI	: the value is less than or equal to 0.0.
38.	CF	: the crack factor is less than 0.0 or greater than 1.0, inclusive.
39.	ASPECT	: the field aspect is not between 0.0 and 360.0 degrees, inclusive.
40.	SLOPE	: the field slope is not between 0.0 and 1.0 (ft/ft).
41.	CONA	: the soil evaporation parameter is not between 0.118 and 0.25, inclusive.

Error 06. The program has read a value for one of the soil depths on one of the sites which is negative or zero. Soil depth is used for soil-water calculations, soil-moisture-tension calculations, percolation, runoff, and indirectly, evapotranspiration. Reenter the number.

Error 07. The value for the ground cover in the parts of the year when there is no plant growth is a proportion. The program has read a value which is not in the 0.0 to 1.0 range and the evaporation during that time of the year will be incorrect.

Error 08. Water is extracted by transpiration from the soil layers in which there are roots. Generation of this error condition means the program has read a rooting depth for one site as negative or zero. Reenter the number.

Error 09. The lowest or bottom soil layer is reserved for use exclusively by the hydrology routines. Roots, therefore, may not extend beyond the bottom of the next-to-last soil layer. The user should total all of the soil layer depths except for the last layer and be sure the value of RD for the site does exceed that total.

Error 10. NOT USED.

Error 11. NOT USED.

Error 12. NOT USED.

Error 13. The plant component uses user-supplied input to control some phenological phenomena. To accomplish this, several critical values (CRIT) are used. The generation of this error means that

$CRIT_{7,S}$ and $CRIT_{8,S}$ have been set equal to the same Julian day for one of the simulated plant species. This will result in a division by zero and consequent abnormal termination of program execution. Check the values being used for $CRIT_{7,S}$ and $CRIT_{8,S}$. Note that different plant species can have the same value for either one or both of these variables.

Error 14. The program has read a value for the optimum temperature for plant activity which is less than the minimum temperature for plant activity for one plant species. This circumstance has no biological reality and renders many of the expressions for plant activity meaningless. Reenter the variable and check the value for minimum plant activity as well.

Error 15. The program has read a value for the optimum temperature for plant activity which is greater than the maximum temperature for plant activity for one plant species. This circumstance has no biological reality and renders many of the expressions for plant activity meaningless. Reenter the variable and check the value for the maximum plant activity as well.

Error 16. The program has summed the areas of all the sites and found that the sum does not equal the specified field area. Stocking rates and forage comsumption by livestock and wildlife will be incorrect if this condition pertains. Be sure the sum of the site areas equals the area of the field.

Error 17. The program has the capacity to simulate nine sites on one field. The program has read a value for the number of sites which is less than zero, meaning the field has no sites, or greater than nine. In either case, the indices and counters within the program will be out of range or yield spurious results. Reenter the value.

Error 18. The program calculates the initial soil water content from the 1/3-bar and 50-bar water content for each soil layer. This value is multiplied by a proportion, STF, which is the fraction of the initial soil water content and is considered the soil water content for day one. If STF is out the range of 0.0 to 1.0, the initial soil water will not be calculated properly. Be sure the variable is in the specified range.

Error 19. The program code can accommodate up to 10 wildlife species. The code has read an integer value for the number of wildlife species that is greater than 10. The user must be sure the number of wildlife species is within the coded limits and that appropriate species-forage-class and location-preference values are in the proper location in subsequent data records.

Error 20. Wildlife species may enter a field on day 1.0. They may not be resident on the field before the beginning of the simulation, which is implied by the date of entry being negative or equal to 0.0. The user should check to be sure the date of entry for every wildlife species is 1.0 or greater.

Error 21. Wildlife species may not remain on the field past the end of the year (day 365 or day 366 for leap years). The program has read a value for one of the wildlife species setting the day the species leaves the field as greater than the last day for the year. The user should understand that some circumstances will allow a year or more of simulation to occur even though this error condition is present. For example, if the user specifies that the beginning year is 1984 (a leap year) and that a wildlife species leaves the field on day 366, he escapes the first test for generation of this error condition done in the initialization subprogram, and the model will simulate one year. However, when control returns to the year loop in the main program, the day for the wildlife species leaving the field is tested again and this time the error condition will occur and program execution terminated. The user should check that no wildlife species remain on the field past the end of the year.

Error 22. The program has read a value for the day a wildlife species leaves the field which indicates it leaves before it arrives. This will yield incorrect loop indices and counters in the program. The user must be sure the difference between the day a wildlife species enters and the day the wildlife species leaves the field is a positive number.

Error 23. Wildlife species serve as forage sinks within the model. A value has been read by the program which indicates that a wildlife species has been given a dry-matter intake (DMI) of less than or equal to 0.0. The user will waste computer time with this condition since all the calculations for the determination of the forage consumed by this wildlife species will be done even if DMI has this value. The user should reenter the value or remove the wildlife species from the simulation.

Error 24. For the beef-growth subprogram to function, certain parameters must be within the bounds of conditions programed into the model. This error condition occurs when the asymptotic growth weight of a cow has been read that is less than 350.0 kg or greater than 800.0 kg. The user should reenter the number.

Error 25. Steers may enter the field on day 1.0. They may not be resident on the field before the beginning of the year, which is implied by the date of entry being negative or 0.0. The user should check to be sure the date of entry for the steers is 1.0 or greater.

Error 26. Steers may not remain on the field past the end of the year. See the discussion of error 21 and substitute the word steers for wildlife.

Error 27. The program has read a value for the day the steers leave the field which indicates they leave before they arrive. This will yield incorrect loop indices and counters in the program. The user must be sure the difference between the day the steers enter and the day the steers leave the field is a positive number.

Error 28. The program has read a value for the age of an entering steer that is less than or equal to 0.0. This is a biological impossibility if the value is negative. If the user does not want to simulate steer growth the steer herd size should be set to 0.0 not the age of a steer. Setting the entering age to 0.0 is waste of computer time. Reenter the number.

Error 29. The program has read a value for the entering weight of the steer that is not consistent with the specified weight at maturity and the entering age of the steer. This means the growth functions programed for the steer will yield incorrect demands for forage. To test the relationship, the user should perform the following calculations:

$$V1 = \frac{WMA}{15.0} \tag{1}$$

$$V2 = 369.5\left[\frac{WMA}{500}\right]^{0.3} \tag{2}$$

$$V3 = V1 + TAVG\ \frac{0.523\ WMA - V1}{V2} \tag{3}$$

$$V4 = \frac{WT}{V3} \tag{4}$$

where WMA is the asymptotic weight of a mature steer in kilograms, TAVG is the entering age of the steer in Julian days, and WT is the entering weight of the steer in kilograms. The value for V4 should fall between 0.75 and 1.25, inclusive, for the relationship among all three variables to be valid. Adjust the values for all three variables until V4 is in the required interval.

Error 30. It does not make realistic management sense to supplement steer diets with a low digestibility feed. The model has been coded to allow diet supplementation only within the digestibility limits of 0.5 to 0.9, inclusive. Reenter this value so that it conforms with this constraint.

Error 31. This is a bookkeeping error and indicates the user may have a record out of order, a value being read in the wrong field, or an incomplete understanding of the problem to be simulated. The user may not try to supplement the diet of steers before the steers arrive on the field.

Error 32. This is a bookkeeping error and indicates the user may have a record out of order, a value being read in the wrong field, or an incomplete understanding of the problem to be simulated. The user may not try to supplement the diet of steers after the steers leave the field.

Error 33. The maximum-melt factor (MFMAX) is less than the minimum-melt factor or is equal to 0.0. The user should check the values of both MFMAX and MFMIN.

Error 34. The minimum-melt factor (MFMIN) is less than 0.0. Reenter the value.

Error 35. The index used to weight antecedent temperature for snow-heat-content calculations is not in the range of 0.0 to 1.0. Values outside of this range can cause errors in heat balance calculations resulting in snowmelt errors. Reenter the value.

Error 36. The value for percent liquid-water holding capacity of the snow (PLWHC) is less than 0.0 or greater than 0.99. This value should be less than 0.05 as this is generally the maximum amount of liquid water that snow can hold against drainage. Reenter the value.

Error 37. The amount of snow water equivalent above which there is 100 percent snow cover (SI) is less than or equal to zero. This may result in erroneous calculations of all new snow accumulation- and melt-related phenomena and should be avoided. Reenter the value.

Error 38. The crack factor (CF) for crack-flow calculations is less than 0.0 or greater than 1.0. This error will cause a soil layer to lose more water if CF is greater than 1.0, or if CF is negative, a soil layer will gain water. Reenter the value.

Error 39. The aspect of the simulated field is not between 0.0 and 360.0 degrees. Reenter the correct value as this variable is used to adjust incoming solar radiation.

Error 40. The average slope for the field is not in the interval between 0.0 and 1.0, inclusive. This slope is used to adjust incoming solar radiation. Reenter the correct value.

Error 41. The value for the soil evaporation parameter is not in the interval 0.118 to 0.25, inclusive. Check the soil type and reenter the correct value.

9. USING THE BASIN-SCALE VERSION TO CHECK FOR ERRORS IN INITIAL CONDITIONS

E.P. Springer, J.W. Skiles

INTRODUCTION

Aside from the errors that occur at compile time or execution time and that are machine, compiler, and often facility specific, the SPUR program can explicitly check for a number of error conditions in the input data. These conditions are brought about by input variables being out of the range of acceptable values or in some instances being equal to each other. However, the user may generate an error condition by including an extra input record, leaving out a specified input record, or having an input variable in an incorrect field.
If the user does receive an error message and SPUR execution is terminated, he or she should first refer to table 9.1 and take the necessary action to remedy the error in the input file(s). If, from the record which holds the variable indicated, the user cannot discern the condition generating the error, the record being read by SPUR should be checked against the record corresponding to the variable being read. For example, if the user omits the parameters for a layer in the soil profile, the program will continue reading the numbers on the subsequent records, until all variables for the soil layers have been read. If the program then attempts to read the site and temperature elevations and the initial proportion of field capacity, but these have been read because of the postulated omission, the program will generate error condition 40 and halt execution. The error generated by the program is not due to the initial field capacity being out of range; rather, it is because an improper number of records is present in the input file. The user must make sure each record specified for input is present in the input file.

If neither of these procedures removes the condition(s) which caused the generation of the error, the user should check that each variable is being read in the format fields specified in tables 3.3, 3.4, and 3.5. Typically, FORTRAN will cease execution if, for instance, two decimal points are read in the same field, or if a minus sign is read after a decimal point. The SPUR program will generate error messages even if none of these circumstances occur. As an example, suppose the user has two numbers on the same record to be read according to a format of 2F6.3. These numbers are 0.009 and 2.14. If the first number is too far to the right by one space, the first variable will be read as 0.00 and the second variable will be read (depending on the FORTRAN for the users' facility) as 92.14 or 902.14. The numbers may be correct, but the SPUR error-checking code will not know that these variables are in improper format fields and will generate the appropriate error message if the values are out of the programed range. The user must be sure that each variable read by SPUR is in the proper field.

The SPUR program, on recognizing an error condition, terminates execution immediately after writing an error message to the SUMARY file. That message has the form:

SPUR EXECUTION TERMINATION BY SPUR DUE TO
***** FATAL CONDITION n *****

where n is a positive integer and is the number of the error condition. The STOP statement in subprogram ERR also has the literal string FATAL ERROR which will be written to the output device in operation at the time of termination. This is machine and facility dependent and may be a LOG file, an output file, a batch listing, or a terminal.

EXPLANATION OF ERRORS

Though many of the error messages given in the table 9.1 are self-explanatory, the user may still wish more information about some. For those users, the following short descriptions of the errors and the suggested action to rectify the condition(s) which generated them follow.

Error 01. The number of channels (NMCHN) is either less than 1 or greater than the maximum number of channels for which the computer code is dimensioned.

Error 02. The number of plant species (NSPEC) is either less than 1 or greater than maximum number of species for which the computer code is dimensioned.

Error 03. The total area of the watershed is greater than 10.0 square miles which is the upper limit of the applicability of the hydrology model.

Error 04. NOT USED.

Error 05. NOT USED.

Error 06. The coefficient for the area-storm-duration relationship, C1, is less than or equal to 0.0. The user should check the input.

Error 07. The exponent for the area-storm duration relationship, C2, is less than or equal to 0.0. The user should check the input.

Error 08. The coefficient for the area-storm runoff-volume relationship, C3, is less than or equal to 0.0. The user should check the input.

Error 09. The exponent for the area-storm runoff-volume relationship, C4, is greater than 0.0. The user should check the input.

Error 10. The coefficient for the peak flow relationship, C5, is less than or equal to 0.0. The user should check the input.

Error 11. The identification number for a channel is less than or equal to 0.0. The user should check channel identification numbers.

Table 9.1
Error codes and variables checked that cause the basin-scale version of SPUR to terminate execution

Error codes	Variables checked	
1.	NMCHN	: number of channels not between 1.0 and MXCHN.
2.	NSPEC	: number of species not between 1.0 and MXCRP.
3.	AREA	: watershed total area greater than 10.0 square miles.
4.	----	: NOT USED.
5.	----	: NOT USED.
6.	C1	: C1 less than or equal to 0.0.
7.	C2	: C2 less than 0.0.
8.	C3	: C3 less than or equal to 0.0.
9.	C4	: C4 greater than 0.0.
10.	C5	: C5 less than or equal to 0.0.
11.	IDCHN	: nonpositive channel identification.
12.	NMFLD	: nonpositive number of fields for a channel.
13.	CHNL	: nonpositive channel length.
14.	CHNW	: nonpositive channel width.
15.	CHNHC	: negative channel hydraulic conductivity.
16.	IDCHN	: duplicate channel identification.
17.	J1/J2	: unknown input channel identification.
18.	J1/J2	: same channel inputs to two or more other channels.
19.	IFLD	: total number of fields greater than MXFLD.
20.	IRPND	: with no pond, nonzero pond report number.
21.	PNDFA	: with no pond, nonzero full pond area.
22.	PNDFV	: with no pond, nonzero full pond volume.
23.	PNDV	: with no pond, nonzero initial pond volume.
24.	PNDHC	: with no pond, nonzero pond hydraulic conductivity.
25.	PNDFA	: with pond, nonpositive full pond area.
26.	PNDFV	: pond, nonpositive full pond volume.
27.	PNDV	: pond, negative initial pond volume.
28.	PNDHC	: pond, negative pond hydraulic conductivity.
29.	IDFLD	: nonpositive field identification.
30.	NMSL	: number of soil layers not between 1 and MXSL.
31.	CF	: crack factor not between 0.0 and 1.0.

Table 9.1--Continued
Error codes and variables checked that cause the basin-scale version of SPUR to terminate execution

Error codes	Variables checked	
32.	FLDA	: nonpositive field area.
33.	S1	: minimum curve number not between 0.0 and 100.0.
34.	S2	: nonpositive return-flow time.
35.	SM15	: nonpositive 15-bar soil-water content.
36.	SM3	: 1/3-bar soil-water content is less than 15-bar soil-water content.
37.	SMO	: soil porosity is less than 1/3-bar soil-water content.
38.	SLSC	: nonpositive saturated-soil conductivity.
39.	SLDTH	: nonpositive soil-layer depth.
40.	STF	: initial fraction of field capacity not between 0.0 and 1.0.
41.	GR	: mulch (residue) cover factor not between 0.0 and 1.0.
42.	RD	: negative root depth.
43.	----	: NOT USED.
44.	FLDK	: USLE soil-erodibility factor not between 0.0 and 1.0.
45.	FLDC	: USLE crop-management factor not between 0.0 and 1.0.
46.	FLDP	: USLE erosion-control-practice factor not between 0.0 and 1.0.
47.	FLDLS	: nonpositive USLE slope-length and -steepness factor.
48.	NPC	: number of particle classes not between zero and MAXPC.
49.	CHNSLP	: channel slope not in the interval 0.0 to 0.40.
50.	XN	: total roughness coefficient not in the interval 0.01 to 0.06.
51.	XNW	: wall-roughness coefficient not in the interval 0.01 to 0.1.
52.	D_{50}	: bed load mean particle size not in the interval 0.2 to 4.0.
53.	FSC	: channel silt-clay fraction not in the interval 0.0 to 0.1.
54.	CAS	: nonpositive reciprocal of silt-clay settling velocity.
55.	DI	: particle-class diameter not in the interval 0.062 to 152.4.
56.	FI/TSW	: nonpositive sediment fraction or sediment fractions do not add up to 1.0 (plus or minus 0.001).
57.	----	: NOT USED.
58.	RAIN	: rainfall on undefined field.
59.	IRCHN	: subbasin report flag not 0 or 1.
60.	IRPND	: pond-report number not between 0 and MXRPND.

Table 9.1--Continued
Error codes and variables checked that cause the basin-scale version of SPUR to terminate execution

Error codes	Variables checked	
61.	IRFLD	: field-report number not between 0 and MXRFLD.
62.	ITFLD	: field type not 0 or 1.
63.	ASPECT	: field aspect not between 0.0 and 360.0 degrees.
64.	SLOPE	: field slope not between 0.0 and 1.0 in (ft/ft).
65.	CONA	: soil evaporation parameter not between 0.118 and 0.25.
66.	CRIT	: $CRIT_{7,S}$ and $CRIT_{8,S}$ are equal in one plant species.
67.	TOPT	: optimum temperature less than minimum for a plant species.
68.	TOPT	: optimum temperature greater than maximum for a plant species.
69.	NWS	: number of wildlife species not in the interval 1 to 10.
70.	TIN	: starting day for a wildlife species is before day 1.0.
71.	TOUT	: ending day for a wildlife species is after year end.
72.	TOUT-TIN	: ending day for a wildlife species is before starting day.
73.	DMI	: amount of dry-matter intake for a wildlife species is less than 0.0.
74.	WMA	: mean asymptotic weight for steer is not between 350.0 and 800.0.
75.	TINS	: starting day for steers is before day 1.0.
76.	TOUTS	: ending day for steers is after year end.
77.	TOUTS-TINS	: ending day for steers is before starting day.
78.	TAVG	: age of steer at turnout is less than or equal to 0.0.
79.	WT	: average initial steer weight will not fit growth curve.
80.	DIGS	: digestibility for supplement not in the interval 0.5 to 0.9.
81.	TS1	: starting day for supplement is before steers are on field.
82.	TS2	: ending day for supplement is after ending day for steers.
83.	MFMAX	: the maximum-melt factor is less than the minimum.
84.	MFMIN	: the minimum-melt factor is less than 0.0.
85.	TIPM	: the antecedent-temperature-weighting factor is not in the interval 0.0 to 1.0.
86.	PLWHC	: the percent liquid water is not in the interval 0.0 to 0.99.
87.	SI	: the water equivalent above which there is 100 percent snow cover is less than or equal to 0.0.

Error 12. The number of fields associated with a channel is less than or equal to 0.0. A channel must have at least one field associated with it. Thus, zero is not a valid number of fields.

Error 13. The length of the channel (CHNL) is less than or equal to 0.0. The channel length is used to calculate the transmission losses so a negative value will result in an error in calculation.

Error 14. The channel width (CHNW) is less than or equal to 0.0. This is used to calculate transmission losses and sediment yield.

Error 15. The value for channel hydraulic conductivity is less than 0.0. The channel hydraulic conductivity is used to calculate transmission losses.

Error 16. A channel identification number was read which was identical to an identification number of a previous channel. The user should review channel identification numbers to find which one corresponds.

Error 17. A channel identification number for an upstream input channel has not been previously read. The order of input is the order of calculation for the channel systems, and if calculations for an input channel have not been completed, the routing of flow through the downstream channel will be incomplete. The user should first check to make sure that there is an input channel. Then if there is an input channel, the order of the input stream will need to be rearranged so that the calculations for the most upstream channels precede those for downstream channels.

Error 18. An upstream input channel can feed only one channel downstream. A condition has been detected in which the same input channel feeds two or more downstream channels. User should check the input stream and correct the order.

Error 19. The total number of fields is greater than the dimensions the computer code can accommodate. User needs to change the dimensions within the computer code to accommodate the larger number of fields, or alter the description of the watershed to fit within the limits.

Error 20. Although a pond was not indicated, an entry was made for the pond-report number. The user should identify the pond input card and change IRPND to 0.0.

Error 21. Although a pond was not indicated, an entry was made for the pond area. The user should identify the pond input card and change PNDFA to 0.0.

Error 22. Although a pond was not indicated, an entry was made for the full pond volume. The user should identify the pond input card and change PNDFY to zero.

Error 23. Although a pond was not indicated, an entry was made for the initial pond volume. The user should identify the pond input card and change PNDV to 0.0.

Error 24. Although a pond was not indicated, an entry was made for the pond hydraulic conductivity. The user should identify the pond input card and change PNDHC to 0.0.

Error 25. The entry for the full pond area (PNDFA) was less than or equal to 0.0. A pond must have a surface area. The user should identify the pond input card and change the value of PNDFA.

Error 26. The entry for the full pond volume (PNDFV) is less than or equal to 0.0. As with area, the pond must have a volume. The user should identify the pond input card and change the volume of PNDFV.

Error 27. The entry for the initial pond volume (PNDV) is less than 0.0. Volume cannot be less than 0.0. The user should identify the pond input card and change the value of PNDV.

Error 28. The entry for pond hydraulic conductivity (PNDHC) is less than 0.0. This variable is used to calculate the seepage out of the bottom of the pond. Negative values are not permitted in the calculations. The user should identify the pond input card and change the value of PNDV.

Error 29. A field identification number (IDFLD) was less than or equal to zero. Field identification numbers must be set for bookkeeping purposes.

Error 30. The number of soil layers exceeded the dimensions of the computer code. The maximum number of soil layers allowed is eight. The user must either reduce the number of layers to fit this constraint or change the dimensions of the program to accommodate more soil layers.

Error 31. The crack factor (CF) for crack flow calculations is less than 0.0 or greater than 1.0. This error will cause a soil layer to lose more water if CF is greater than 1.0. If CF is negative, a soil layer will gain water. Reenter the value.

Error 32. The area for a field has been entered as either a negative number or 0.0. The user should reenter the proper value.

Error 33. The program has read a value for the condition-I curve number (CN_I) that is outside of the range 0.0 to 100.0, inclusive. If CN_I is less than 0.0, the value of SMX in subprogram FLDHYD will have the wrong sign. If the value of CN_I exceeds 100.0, it will cause SMX to be too small. The result is that runoff for the site for which the illegal value was read will be incorrect. Adjust this value so that it is within the specified range.

Error 34. A return flow parameter has been read with a value less than 0.0. The value must be greater than or equal to 0.0 for proper water balance calculations. The user should reenter a correct value.

Error 35. The program has read a negative value for the 15-bar soil-water content for one of the soil layers at one of the sites. The units for this variable cancel (inches per inch). The initial soil-water calculation per layer per site requires the use of this variable as does the calculation for the 50-bar water content. Review the site description for the simulated site and reenter the value.

Error 36. The program has read a value for the 1/3-bar water content that is less than that of the 15-bar water content. The 1/3-bar water content is used in the same calculations as the 15-bar water content and is unitless. (See error 35.) Review the site description for the simulated site and reenter the value.

Error 37. The program has read a value for the soil porosity that is less than or equal to the 1/3-bar water content. The soil porosity is used in the same calculations as the 1/3-bar and the 15-bar water content values and also in the calculation of the soil bulk density. It is unitless as well. Review the site description for the simulated site and reenter the value.

Error 38. The program has read a value for the saturated-soil conductivity which is negative. This parameter is used in the calculation of soil-water percolation. A negative value will cause an increase in soil water content of a soil layer rather than a decrease. Reenter the value.

Error 39. The program has read a value for one of the soil depths on one of the sites which is negative or 0.0. Soil depth is used for soil-water calculations, soil-moisture-tension calculations, percolation, runoff, and indirectly, evapotranspiration. Reenter the number.

Error 40. The program calculates the initial soil water content from the 1/3-bar and 50-bar water content for each soil layer. This value is multiplied by a proportion (STF) which is the fraction of that initial content and is considered the soil water for day one of the simulation. If STF is out the range of 0.0 to 1.0, the initial soil water will not be calculated properly. Be sure the variable is in the specified range.

Error 41. The value for the mulch-cover factor, to adjust soil-water evaporation in the parts of the year when there is no plant growth, is a proportion. The program has read a value which is not in the 0.0 to 1.0 range and the evaporation during that time of the year will be incorrect.

Error 42. Water is extracted by transpiration from the soil layers in which there are roots. Generation of this error condition means the program has read a rooting depth for one site which is negative or 0.0. Reenter the number.

Error 43. NOT USED.

Error 44. The range of values for the USLE K factor is not between 0.0 and 1.0. See Wischmeier and Smith (1978) for a nomograph to calculate values for the K factor.

Error 45. The USLE crop-management factor is not in the range of 0.0 to 1.0. See Wischmeier and Smith (1978) for tabular values.

Error 46. The USLE erosion-control-practice factor is not in the range of 0.0 to 1.0. This value should be 1.0 unless a conservation practice such as terracing or contour furrowing has been used. See Wischmeier and Smith (1978) for proper values.

Error 47. The USLE slope length is not positive. Recheck the calculations.

Error 48. The number of particle-sized classes for the sediment material in the stream bed is not in the interval between zero and MAXPC, the maximum number of particle classes. The user should reenter the value for NPC to conform to the stated limits.

Error 49. The value entered for the channel slope is not in the interval between 0.0 and 0.40. The channel slope is important to the sediment calculations and these limits are set for model applicability. The user can adjust the slope by dividing the channel into more or less segments and recalculating the slope.

Error 50. The total roughness coefficient, Manning's n value, is not in the interval 0.01 to 0.06, inclusive. This variable is important in determining the limitations of the sediment transport model. Check the tables and reenter the value.

Error 51. The wall-roughness coefficient, Manning's n value, is not in the interval 0.01 to 0.1, inclusive. This variable is important in determining the sediment transport rate. User should check the tables and reenter the value.

Error 52. The median particle size of bed material is not in the interval 0.2 to 4.0 mm, inclusive. This is a limitation of the sediment transport routines. A value out of this interval may mean that the model is not appropriate for the area being simulated.

Error 53. The fraction of sediment material in the silt-clay class is not in the interval 0.0 to 0.1, inclusive. This is a limitation of the sediment transport routines. A value out of this interval may mean that the model is not appropriate for the area being simulated.

Error 54. The reciprocal of the silt-clay settling velocity is less than 0.0. This is an error in entering the variable. Check the value and reenter it.

Error 55. The particle-class diameters do not fall into the interval from 0.062 to 152.4 mm, inclusive. This is a limitation of the sediment transport routines. A value outside of this interval may mean that the model is not appropriate for the area being simulated.

Error 56. The sum of the sediment classes in the bed divided by (1.0 - FSC) did not add to 1.0 + 0.001. The user should check the particle-class fractions and correct the values accordingly.

Error 57. NOT USED.

Error 58. A field on which rainfall can occur has not been defined. Reenter the value for the field identification or check the rainfall data file.

Error 59. The report flag for a subbasin should be either zero (for no report) or 1 (for a report). A value other than these has been entered. The user should reenter an appropriate value.

Error 60. The report flag for ponds takes values to the maximum number of pond reports allowed, MXRPND. A pond report number has been entered which is not in the interval between zero and MXRPND. The user should check and reenter the appropriate value.

Error 61. Field reports are the same as pond reports. Each field report is given a number so that the desired fields can be grouped under the same reports, for example, all lateral fields group together. The program has read an entry which is either less than zero or greater than the maximum number of reports allowed. Reenter the correct values.

Error 62. The field type, either an upland (0) or lateral (1), has not been correctly assigned. The user should check the values and enter the correct type.

Error 63. The aspect for the field is not between 0.0 and 360.0 degrees. Reenter a correct value as this variable is used to adjust incoming solar radiation.

Error 64. The average surface slope is not in the interval 0.0 to 1.0, inclusive. This variable is used to adjust incoming solar radiation. Reenter a correct value.

Error 65. The value for the soil evaporation parameter, CONA, is not in the suggested interval. Check the soil type and reenter the correct value.

Error 66. The plant component uses user-supplied input to control some phenological phenomena. To accomplish this, several critical values (stored in the CRIT matrix) are used. The generation of this error means that $CRIT_{7,S}$ and $CRIT_{8,S}$ have been set equal to the same Julian day for one of the simulated plant species. This will result in a division by zero and consequent abnormal termination of program execution. Check the values being used for $CRIT_{7,S}$ and $CRIT_{8,S}$. Note that different plant species can have the same value for either one or both of these variables.

Error 67. The program has read a value for the optimum temperature for plant activity that is less than the minimum temperature for plant activity for one plant species. This condition has no biological reality and renders many of the expressions for plant activity meaningless. Reenter the variable and check the value for minimum plant activity as well.

Error 68. The program has read a value for the optimum temperature for plant activity that is greater than the maximum temperature for plant activity for one plant species. This condition has no biological reality and renders many of the expressions for plant activity meaningless. Reenter the variable and check the value for the maximum plant activity as well.

Error 69. The program code can accommodate up to ten wildlife species. The code has read an integer value for the number of wildlife species that is greater than ten. The user must be sure the number of wildlife species is within the coded limits and he must be sure that appropriate species-forage-class and location-preference values are in the proper location in subsequent data records.

Error 70. Wildlife species may not be resident on the field before the beginning of the simulation, which is implied by the date of entry being negative or equal to 0.0. The user should check to be sure the date of entry for every wildlife species is 1.0 or greater.

Error 71. Wildlife species may not remain on the field past the end of the year (day 365 or day 366 for leap years). The program has read a value for one of the wildlife species setting the day the species leaves the field as greater than the last day for the year. The user should understand that some circumstances will allow a year or more of simulation to occur even though this error condition is present. For example, if the user specifies that the beginning year is 1984 (a leap year) and that a wildlife species leaves the field on day 366, he or she escapes the first test for generation of this error condition done in the initialization subprogram, and the model will simulate one year. However, when control returns to the year loop in the main program, the day for the wildlife species leaving the field is tested again and this time the error condition will occur; program execution will be terminated. The user should check that no wildlife species remain on the field past the end of the year.

Error 72. The program has read a value for the day a wildlife species leaves the field that indicates it leaves before it arrives. This will yield incorrect loop indices and counters in the program. The user must be sure the difference between the day a wildlife species enters and the day the wildlife species leaves the field is a positive number.

Error 73. Wildlife species serve as forage sinks within the model. A value has been read by the program that indicates that a wildlife species has been given a dry-matter intake (DMI) of less than or equal to 0.0. The user will waste computer time with this condition since all the calculations for the determination of the forage consumed by this wildlife species will be done even if DMI has this value. The user should reenter the value or remove the wildlife species from the simulation.

Error 74. For the beef-growth subprogram to function, certain parameters must be within the bounds of conditions programed into the model. This error condition occurs when the asymptotic growth weight of a cow has been read that is less than 350.0 kilograms or greater than 800.0 kilograms. The user should reenter the number.

Error 75. Steers may enter the field on day 1.0. They may not be resident on the field before the beginning of the year, which is implied by the date of entry being negative or 0.0. The user should check to be sure the date of entry for the steers is 1.0 or greater.

Error 76. Steers may not remain on the field past the end of the year. See error 71 and substitute the word steers for wildlife.

Error 77. The program has read a value for the day the steers leave the field that indicates they leave before they arrive. This will yield incorrect loop indices and counters in the program. The user must be sure the difference between the day the steers enter and the day the steers leave the field is a positive number.

Error 78. The program has read a value for the age of an entering steer that is less than or equal to 0.0. This is a biological impossibility if the value is negative. If the user does not want to simulate steer growth, the steer herd size, not the age of a steer, should be set to zero. Setting the entering age to 0.0 is waste of computer time. Reenter the number.

Error 79. The program has read a value for the entering weight of the steer that is not consistent with the specified weight at maturity and the entering age of the steer. This means the growth functions programed for the steer will yield incorrect demands for forage. To test the relationship, the user should perform the following calculatations:

$$V1 = \frac{WMA}{15.0} \qquad (1)$$

$$V2 = 369.5\left[\frac{WMA}{500}\right]^{0.3} \qquad (2)$$

$$V3 = V1 + TAVG\,\frac{0.523\,WMA - V1}{V2} \qquad (3)$$

$$V4 = \frac{WT}{V3} \qquad (4)$$

where WMA is the asymptotic weight of a mature steer in kilograms, TAVG is the entering age of the steer in julian days, and WT is the entering weight of the steer in kilograms. The value for V4 should fall between 0.75 and 1.25, inclusive, for the relationship among all three variables to be valid. Adjust the values for all three variables until V4 is in the required interval.

Error 80. It does not make realistic management sense to supplement steer diets with a low digestibility feed. The model has been coded to allow diet supplementation only within the digestibility limits of 0.5 to 0.9, inclusive. Reenter this value so that it conforms with this constraint.

Error 81. This is a bookkeeping error and indicates the user may have a record out of order, a value being read in the wrong field, or an incomplete understanding of the problem to be simulated. The user may not try to supplement the diet of steers before the steers arrive on the field.

Error 82. This is a bookkeeping error and indicates the user may have a record out of order, a value being read in the wrong field, or an incomplete understanding of the problem to be simulated. The user may not try to supplement the diet of steers after the steers leave the field.

Error 83. The maximum-melt factor (MFMAX) is less than the minimum-melt factor or is equal to 0.0. The user should check the values of both MFMAX and MFMIN.

Error 84. The minimum-melt factor (MFMIN) is less than 0.0. Reenter the value.

Error 85. The index used to weight antecedent temperature for snow-heat-content calculations is not in the range of 0.0 to 1.0. Values outside of this range can cause errors in heat balance calculations resulting in snowmelt errors. Reenter the value.

Error 86. The value for percent liquid-water holding capacity of the snow (PLWHC) is less than 0.0 or greater than 0.99. This value should be less than 0.05 as this is generally the maximum amount of liquid water that snow can hold against drainage. Reenter the value.

Error 87. The amount of snow water equivalent above which there is 100 percent snow cover (SI) is less than or equal to 0.0. This may result in erroneous calculations of all new snow accumulation- and melt-related phenomena and should be avoided. Reenter the value.

10. PARAMETER ESTIMATION FOR THE CLIMATE GENERATOR

C.L. Hanson, C.W. Richardson

INTRODUCTION

The procedures necessary for estimating parameter values used to generate sets of synthetic climatic data are discussed in this chapter. These procedures can be used to estimate values for the variables on cards 4 through 15 in table 4.1 in chapter 4.

The variables are as follows:

- PWW - the probability of a wet day preceded by a wet day for each month.
- PWD - the probability of a wet day preceded by a dry day for each month.
- ALPHA - gamma-distribution parameter for each month.
- BETA - gamma-distribution parameter for each month.
- TXMD - mean of TMAX on dry days.
- ATX - amplitude of TMAX on wet or dry days.
- CVTX - mean of coefficient of variation of TMAX on wet or dry days.
- ACVTX - amplitude of coefficient of variation of TMAX on wet or dry days.
- TXMW - mean of TMAX on wet days.
- TN - mean of TMIN on wet or dry days.
- ATN - amplitude of TMIN on wet or dry days.
- CVTN - mean of coefficient of variation of TMIN on wet or dry days.
- ACVTN - amplitude of coefficient of variation of TMIN on wet or dry days.
- RMD - mean of solar radiation on dry days.
- AR - amplitude of solar radiation on wet or dry days.
- RMW - mean of solar radiation on wet days.
- AVEL - mean wind speed for the year (mph).
- ASD - standard deviation of the hourly wind speed on an annual basis.
- VEL(1)-VEL(12) - mean wind speed for months 1 through 12.

PRECIPITATION

The variables PWW, PWD, ALPHA, and BETA are required to generate daily precipitation series. Values for the variables P(W/W), P(W/D), alpha, and beta for 139 stations in the conterminous United States are given in table 10.1. The program GENPAR (see Chapter 4) can be used to calculate the variable values from the precipitation record at a site. At least 20 years of record should be available before using GENPAR. At sites where records are not available, variable values can be calculated using GENPAR for nearby sites and then the desired site variables can be estimated by interpolation. In mountainous terrain, this interpolation procedure should be used with caution.

MAXIMUM AND MINIMUM TEMPERATURE AND SOLAR RADIATION

The program GENPAR can be used to compute values for the variables previously listed for maximum and minimum temperature and solar radiation when records are available from a specific site. At least 10 years of data should be available before using GENPAR to compute variable values for temperature and solar radiation.

When site data are not available, as for much of the rangeland, values of maximum and minimum temperature and solar radiation variables can be obtained from figures 10.1 through 10.12. This is done by locating the site on the maps and selecting a value from the appropriate isogram. When the site is between isograms, the value should be obtained by interpolation.

WIND SPEED

Fourteen variable values are required in the wind run subprogram WINDGN, which is called by CLIMGN. These variables are mean annual wind speed (AVEL), standard deviation of the hourly wind speed (ASD), and the mean wind speed for each month (VEL(1)-VEL(12)). These values can be computed for sites where data are available or values from nearby sites may be used as estimates.

Another procedure is to use the Climatic Atlas of the United States (U.S. Department of Commerce 1968) which contains values of the mean daily wind speed for each month, VEL(1)-VEL(12), the mean annual wind speed, AVEL, and the standard deviation of hourly wind speed on an annual basis, ASD, (v_i, v_y, and s_h, respectively, in Chapter 2, Part I) for many locations. These variables are available from tables on pages 73-78 of the Climatic Atlas.

LITERATURE CITED

U.S. Department of Commerce. 1968. Climatic Atlas of the United States. Environmental Science Services Administration, Environmental Data Services, National Climatic Center, Ashville, NC, 80 p.

Table 10.1
Rainfall generation parameters for State and station by month

Variable	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
AL BIRMINGHAM												
P(W/W)	0.491	0.505	0.475	0.444	0.530	0.481	0.548	0.426	0.480	0.395	0.497	0.495
P(W/D)	0.264	0.299	0.285	0.245	0.183	0.220	0.307	0.265	0.175	0.144	0.213	0.267
ALPHA	0.643	0.640	0.648	0.712	0.675	0.626	0.802	0.660	0.676	0.630	0.715	0.647
BETA	0.710	0.765	0.845	0.724	0.662	0.699	0.499	0.629	0.744	0.716	0.593	0.769
AL MOBILE												
P(W/W)	0.419	0.483	0.514	0.340	0.419	0.547	0.593	0.515	0.538	0.444	0.375	0.493
P(W/D)	0.294	0.286	0.257	0.197	0.202	0.280	0.446	0.351	0.232	0.135	0.193	0.271
ALPHA	0.577	0.629	0.556	0.512	0.644	0.623	0.713	0.686	0.548	0.645	0.613	0.624
BETA	0.766	0.816	0.969	1.434	0.902	0.799	0.697	0.774	1.109	0.659	0.628	0.894
AL MONTGOMERY												
P(W/W)	0.447	0.456	0.435	0.380	0.475	0.457	0.436	0.408	0.514	0.444	0.348	0.471
P(W/D)	0.269	0.289	0.262	0.219	0.185	0.220	0.317	0.264	0.166	0.117	0.175	0.279
ALPHA	0.713	0.691	0.699	0.634	0.634	0.706	0.620	0.762	0.546	0.601	0.684	0.691
BETA	0.525	0.680	0.786	0.852	0.681	0.589	0.648	0.408	1.179	0.767	0.619	0.687
AZ FLAGSTAFF												
P(W/W)	0.558	0.470	0.483	0.464	0.362	0.490	0.545	0.515	0.438	0.470	0.495	0.536
P(W/D)	0.114	0.138	0.151	0.127	0.073	0.051	0.254	0.279	0.132	0.082	0.114	0.115
ALPHA	0.895	0.889	0.854	0.945	0.983	0.592	0.826	0.782	0.659	0.811	0.689	0.729
BETA	0.327	0.292	0.318	0.257	0.187	0.423	0.283	0.324	0.452	0.347	0.436	0.510
AZ PHOENIX												
P(W/W)	0.407	0.478	0.364	0.303	0.294	0.313	0.366	0.318	0.429	0.354	0.027	0.400
P(W/D)	0.085	0.077	0.070	0.042	0.018	0.022	0.099	0.147	0.057	0.054	0.060	0.078
ALPHA	0.825	0.822	0.998	0.883	0.899	0.629	0.752	0.650	0.532	0.680	0.917	0.746
BETA	0.225	0.182	0.242	0.199	0.140	0.271	0.233	0.335	0.462	0.310	0.220	0.323
AZ YUMA												
P(W/W)	0.273	0.077	0.250	0.176	0.000	0.000	0.238	0.211	0.313	0.318	0.222	0.349
P(W/D)	0.056	0.048	0.041	0.024	0.008	0.000	0.030	0.052	0.017	0.025	0.038	0.047
ALPHA	0.841	0.763	0.998	0.517	0.802	0.000	0.637	0.670	0.394	0.686	0.624	0.862
BETA	0.180	0.205	0.102	0.332	0.127	0.000	0.248	0.253	0.875	0.327	0.276	0.197
AR FORT SMITH												
P(W/W)	0.426	0.444	0.394	0.479	0.445	0.407	0.421	0.341	0.432	0.366	0.423	0.444
P(W/D)	0.157	0.216	0.238	0.280	0.245	0.210	0.195	0.171	0.171	0.134	0.147	0.165
ALPHA	0.655	0.701	0.719	0.709	0.658	0.632	0.590	0.650	0.752	0.625	0.638	0.719
BETA	0.447	0.501	0.574	0.624	0.796	0.674	0.762	0.730	0.604	0.956	0.803	0.534
AR LITTLE ROCK												
P(W/W)	0.489	0.437	0.500	0.498	0.500	0.480	0.401	0.383	0.396	0.367	0.392	0.462
P(W/D)	0.217	0.267	0.242	0.270	0.190	0.179	0.233	0.177	0.174	0.154	0.186	0.225
ALPHA	0.619	0.681	0.790	0.686	0.554	0.651	0.703	0.581	0.624	0.659	0.633	0.665
BETA	0.699	0.708	0.564	0.730	1.090	0.664	0.600	0.710	0.909	0.628	0.823	0.694
CA BAKERSFIELD												
P(W/W)	0.425	0.482	0.346	0.474	0.297	0.444	0.300	0.250	0.214	0.391	0.364	0.303
P(W/D)	0.132	0.132	0.130	0.095	0.039	0.008	0.010	0.006	0.019	0.022	0.082	0.117
ALPHA	0.966	0.827	0.845	0.822	0.841	0.805	0.800	0.796	0.893	0.967	0.999	0.913
BETA	0.175	0.215	0.162	0.214	0.115	0.112	0.090	0.063	0.135	0.255	0.232	0.155
CA BLUE CANYON												
P(W/W)	0.731	0.678	0.663	0.631	0.556	0.488	0.067	0.296	0.370	0.437	0.628	0.710
P(W/D)	0.208	0.213	0.231	0.184	0.155	0.073	0.025	0.032	0.054	0.090	0.200	0.174
ALPHA	0.716	0.808	0.880	0.721	0.798	0.742	0.996	0.439	0.600	0.567	0.710	0.791
BETA	1.597	1.053	0.798	0.777	0.463	0.350	0.070	0.615	0.456	1.694	1.188	1.432

Table 10.1--Continued
Rainfall generation parameters for State and station by month

Variable	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
CA EUREKA												
P(W/W)	0.754	0.693	0.724	0.615	0.518	0.398	0.122	0.306	0.397	0.529	0.691	0.718
P(W/D)	0.331	0.265	0.261	0.209	0.167	0.128	0.064	0.058	0.095	0.177	0.272	0.266
ALPHA	0.837	0.758	0.968	0.777	0.743	0.777	0.998	0.499	0.651	0.851	0.719	0.877
BETA	0.556	0.506	0.331	0.359	0.295	0.150	0.050	0.289	0.275	0.379	0.622	0.510
CA FRESNO												
P(W/W)	0.509	0.519	0.393	0.477	0.340	0.158	0.160	0.150	0.154	0.286	0.484	0.475
P(W/D)	0.172	0.156	0.140	0.105	0.056	0.024	0.010	0.010	0.017	0.034	0.098	0.154
ALPHA	0.724	0.759	0.852	0.752	0.998	0.998	0.998	0.698	0.848	0.862	0.827	0.755
BETA	0.384	0.333	0.313	0.357	0.134	0.076	0.080	0.095	0.187	0.287	0.351	0.336
CA MT. SHASTA												
P(W/W)	0.718	0.675	0.646	0.591	0.563	0.466	0.258	0.378	0.386	0.490	0.628	0.689
P(W/D)	0.233	0.211	0.206	0.154	0.137	0.101	0.042	0.049	0.049	0.097	0.200	0.185
ALPHA	0.776	0.650	0.729	0.706	0.834	0.998	0.998	0.994	0.558	0.635	0.660	0.623
BETA	0.724	0.782	0.461	0.471	0.284	0.182	0.150	0.188	0.607	0.593	0.842	0.962
CA SAN DIEGO												
P(W/W)	0.580	0.388	0.427	0.465	0.396	0.190	0.250	0.333	0.368	0.250	0.479	0.458
P(W/D)	0.124	0.131	0.139	0.106	0.047	0.026	0.006	0.010	0.019	0.046	0.103	0.111
ALPHA	0.683	0.659	0.737	0.734	0.867	0.998	0.998	0.617	0.847	0.578	0.785	0.708
BETA	0.398	0.392	0.301	0.235	0.084	0.064	0.040	0.233	0.223	0.230	0.318	0.373
CA SAN FRANCISCO												
P(W/W)	0.662	0.602	0.566	0.515	0.429	0.250	0.091	0.238	0.280	0.385	0.587	0.680
P(W/D)	0.225	0.193	0.203	0.121	0.063	0.042	0.016	0.030	0.028	0.090	0.168	0.166
ALPHA	0.725	0.762	0.762	0.803	0.744	0.512	0.900	0.769	0.486	0.535	0.702	0.761
BETA	0.550	0.385	0.338	0.329	0.199	0.254	0.150	0.083	0.420	0.478	0.423	0.487
CO COLORADO SPRINGS												
P(W/W)	0.333	0.400	0.467	0.456	0.530	0.487	0.521	0.559	0.423	0.424	0.366	0.329
P(W/D)	0.098	0.123	0.173	0.159	0.232	0.235	0.400	0.253	0.140	0.111	0.098	0.087
ALPHA	0.905	0.998	0.850	0.656	0.601	0.607	0.708	0.755	0.716	0.774	0.885	0.988
BETA	0.077	0.068	0.114	0.264	0.361	0.380	0.300	0.278	0.302	0.224	0.141	0.070
CO DENVER												
P(W/W)	0.423	0.384	0.503	0.483	0.540	0.443	0.435	0.373	0.419	0.408	0.427	0.394
P(W/D)	0.130	0.177	0.201	0.202	0.208	0.246	0.237	0.228	0.149	0.113	0.122	0.126
ALPHA	0.781	0.853	0.790	0.655	0.611	0.637	0.634	0.600	0.693	0.690	0.948	0.988
BETA	0.118	0.152	0.179	0.292	0.453	0.295	0.333	0.278	0.292	0.312	3.149	0.093
CO GRAND JUNCTION												
P(W/W)	0.407	0.410	0.388	0.404	0.476	0.427	0.318	0.384	0.391	0.475	0.385	0.344
P(W/D)	0.173	0.183	0.179	0.168	0.107	0.086	0.114	0.184	0.136	0.107	0.127	0.169
ALPHA	0.947	0.994	0.998	0.849	0.821	0.835	0.764	0.794	0.840	0.983	0.918	0.973
BETA	0.096	0.089	0.093	0.128	0.150	0.155	0.121	0.189	0.176	0.172	0.131	0.099
CO PUEBLO												
P(W/W)	0.362	0.411	0.455	0.404	0.455	0.417	0.370	0.417	0.301	0.372	0.292	0.435
P(W/D)	0.104	0.113	0.136	0.116	0.172	0.180	0.246	0.230	0.143	0.092	0.093	0.071
ALPHA	0.935	0.998	0.966	0.634	0.650	0.693	0.720	0.615	0.661	0.719	0.939	0.928
BETA	0.066	0.065	0.100	0.327	0.322	0.227	0.294	0.346	0.246	0.322	0.141	0.091
CT HARTFORD (WINDSOR LOCKS)												
P(W/W)	0.406	0.454	0.445	0.475	0.412	0.469	0.356	0.387	0.444	0.421	0.513	0.493
P(W/D)	0.311	0.311	0.301	0.310	0.309	0.295	0.275	0.274	0.236	0.182	0.297	0.297
ALPHA	0.780	0.650	0.755	0.689	0.725	0.667	0.702	0.594	0.556	0.641	0.687	0.694
BETA	3.555	0.485	0.487	0.504	0.369	0.454	0.467	0.718	0.750	0.694	0.530	0.506

Table 10.1--Continued
Rainfall generation parameters for State and station by month

Variable	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
DE WILMINGTON												
P(W/W)	0.450	0.410	0.451	0.482	0.462	0.393	0.401	0.420	0.437	0.428	0.460	0.476
P(W/D)	0.263	0.282	0.312	0.318	0.291	0.244	0.251	0.244	0.172	0.162	0.245	0.226
ALPHA	0.783	0.727	0.732	0.771	0.692	0.674	0.578	0.684	0.592	0.667	0.699	0.746
BETA	0.335	0.435	0.468	0.377	0.364	0.537	0.774	0.655	0.852	0.550	0.514	0.494
DC WASHINGTON												
P(W/W)	0.424	0.415	0.452	0.478	0.455	0.377	0.400	0.441	0.406	0.394	0.361	0.410
P(W/D)	0.265	0.254	0.303	0.276	0.260	0.269	0.243	0.231	0.179	0.162	0.242	0.244
ALPHA	0.834	0.811	0.828	0.789	0.751	0.622	0.581	0.607	0.635	0.628	0.731	0.679
BETA	0.299	0.384	0.387	0.383	0.423	0.604	0.793	0.810	0.645	0.610	0.478	0.508
FL JACKSONVILLE												
P(W/W)	0.401	0.398	0.408	0.320	0.477	0.564	0.555	0.584	0.598	0.505	0.330	0.370
P(W/D)	0.212	0.253	0.190	0.172	0.181	0.294	0.391	0.342	0.320	0.200	0.157	0.191
ALPHA	0.677	0.731	0.626	0.670	0.586	0.651	0.676	0.613	0.622	0.545	0.665	0.677
BETA	0.486	0.670	0.693	0.676	0.770	0.800	0.706	0.926	0.795	0.869	0.419	0.500
FL MIAMI												
P(W/W)	0.328	0.364	0.286	0.345	0.597	0.631	0.624	0.599	0.697	0.650	0.359	0.360
P(W/D)	0.182	0.173	0.174	0.160	0.196	0.413	0.382	0.422	0.401	0.319	0.196	0.142
ALPHA	0.622	0.634	0.662	0.611	0.601	0.679	0.707	0.635	0.631	0.549	0.549	0.562
BETA	0.553	0.577	0.513	0.735	1.091	0.914	0.559	0.657	0.799	1.027	0.680	0.533
FL TALLAHASSEE												
P(W/W)	0.387	0.433	0.404	0.379	0.483	0.573	0.633	0.577	0.500	0.437	0.344	0.387
P(W/D)	0.241	0.286	0.225	0.187	0.206	0.304	0.496	0.329	0.254	0.110	0.163	0.219
ALPHA	0.744	0.696	0.628	0.591	0.722	0.652	0.670	0.745	0.555	0.656	0.625	0.696
BETA	0.583	0.830	0.973	0.901	0.628	0.836	0.727	0.665	1.288	0.903	0.768	0.780
FL TAMPA												
P(W/W)	0.309	0.409	0.397	0.370	0.359	0.568	0.602	0.583	0.553	0.438	0.327	0.267
P(W/D)	0.180	0.201	0.169	0.118	0.169	0.270	0.436	0.474	0.350	0.178	0.132	0.181
ALPHA	0.669	0.719	0.631	0.687	0.578	0.655	0.624	0.701	0.632	0.672	0.641	0.687
BETA	0.526	0.634	0.951	0.621	0.758	0.713	0.811	0.668	0.719	0.490	0.646	0.497
GA ATLANTA												
P(W/W)	0.502	0.490	0.433	0.426	0.462	0.473	0.548	0.437	0.490	0.561	0.385	0.468
P(W/D)	0.261	0.291	0.286	0.247	0.188	0.258	0.318	0.208	0.163	0.119	0.207	0.258
ALPHA	0.718	0.727	0.689	0.723	0.728	0.765	0.681	0.711	0.661	0.622	0.668	0.743
BETA	0.566	0.618	0.734	0.717	0.613	0.453	0.571	0.561	0.671	0.627	0.621	0.589
GA AUGUSTA												
P(W/W)	0.477	0.434	0.473	0.436	0.503	0.492	0.532	0.437	0.458	0.482	0.414	0.456
P(W/D)	0.232	0.290	0.253	0.220	0.183	0.227	0.271	0.233	0.180	0.113	0.165	0.220
ALPHA	0.733	0.797	0.689	0.637	0.754	0.813	0.614	0.641	0.694	0.643	0.618	0.738
BETA	0.528	0.537	0.654	0.657	0.556	0.511	0.696	0.695	0.632	0.558	0.463	0.489
GA MACON												
P(W/W)	0.468	0.519	0.478	0.398	0.524	0.472	0.559	0.502	0.503	0.492	0.370	0.442
P(W/D)	0.250	0.283	0.263	0.214	0.182	0.257	0.340	0.239	0.184	0.118	0.176	0.248
ALPHA	0.701	0.799	0.666	0.632	0.597	0.637	0.692	0.751	0.623	0.594	0.734	0.756
BETA	0.527	0.559	0.710	0.693	0.730	0.630	0.511	0.472	0.631	0.653	0.437	0.580
GA SAVANAH												
P(W/W)	0.439	0.417	0.418	0.321	0.452	0.551	0.577	0.551	0.502	0.463	0.375	0.331
P(W/D)	0.229	0.283	0.251	0.194	0.203	0.264	0.394	0.292	0.244	0.131	0.158	0.215
ALPHA	0.737	0.718	0.710	0.712	0.626	0.689	0.671	0.653	0.622	0.582	0.600	0.795
BETA	0.456	0.499	0.602	0.623	0.861	0.775	0.798	0.823	0.825	0.692	0.474	0.434

Table 10.1--Continued
Rainfall generation parameters for State and station by month

Variable	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
ID BOISE												
P(W/W)	0.595	0.559	0.459	0.406	0.476	0.464	0.250	0.353	0.370	0.389	0.534	0.543
P(W/D)	0.317	0.235	0.223	0.211	0.196	0.150	0.053	0.063	0.083	0.152	0.213	0.271
ALPHA	0.846	0.920	0.998	0.841	0.740	0.854	0.826	0.676	0.801	0.998	0.998	0.883
BETA	0.148	0.115	0.101	0.180	0.211	0.176	0.113	0.202	0.159	0.115	0.139	0.128
ID POCATELLO												
P(W/W)	0.511	0.524	0.479	0.380	0.508	0.509	0.286	0.360	0.353	0.370	0.450	0.548
P(W/D)	0.289	0.253	0.230	0.213	0.194	0.169	0.095	0.107	0.099	0.110	0.194	0.259
ALPHA	0.949	0.998	0.998	0.998	0.794	0.824	0.850	0.706	0.836	0.884	0.987	0.992
BETA	0.097	0.080	0.082	0.145	0.167	0.185	0.111	0.199	0.146	0.165	0.111	0.090
IL CHICAGO												
P(W/W)	0.430	0.430	0.485	0.559	0.441	0.458	0.437	0.357	0.455	0.456	0.460	0.483
P(W/D)	0.291	0.285	0.330	0.332	0.293	0.288	0.270	0.202	0.214	0.193	0.236	0.274
ALPHA	0.681	0.782	0.705	0.733	0.783	0.692	0.602	0.689	0.718	0.640	0.735	0.666
BETA	0.251	0.206	0.297	0.424	0.357	0.548	0.735	0.652	0.500	0.537	0.325	0.280
IN EVANSVILLE												
P(W/W)	0.467	0.457	0.485	0.483	0.493	0.459	0.455	0.393	0.418	0.446	0.440	0.490
P(W/D)	0.242	0.276	0.288	0.336	0.252	0.243	0.263	0.181	0.170	0.166	0.214	0.260
ALPHA	0.673	0.725	0.622	0.669	0.697	0.676	0.743	0.654	0.629	0.659	0.707	0.648
BETA	0.479	0.472	0.635	0.509	0.608	0.508	0.517	0.593	0.604	0.504	0.507	0.528
IN FORT WAYNE												
P(W/W)	0.496	0.463	0.552	0.535	0.502	0.493	0.439	0.393	0.424	0.434	0.461	0.498
P(W/D)	0.326	0.309	0.359	0.389	0.305	0.253	0.297	0.217	0.238	0.202	0.277	0.313
ALPHA	0.667	0.676	0.743	0.781	0.830	0.838	0.713	0.762	0.758	0.653	0.830	0.668
BETA	0.280	0.294	0.275	0.346	0.385	0.435	0.489	0.467	0.359	0.525	0.313	0.279
IN INDIANAPOLIS												
P(W/W)	0.466	0.462	0.496	0.543	0.513	0.421	0.406	0.358	0.415	0.428	0.412	0.518
P(W/D)	0.291	0.277	0.344	0.332	0.304	0.266	0.273	0.218	0.192	0.175	0.259	0.291
ALPHA	0.630	0.692	0.688	0.749	0.845	0.671	0.746	0.753	0.646	0.689	0.733	0.669
BETA	0.387	0.362	0.423	0.430	0.390	0.578	0.582	0.437	0.580	0.507	0.461	0.375
IA DES MOINES												
P(W/W)	0.391	0.397	0.490	0.466	0.455	0.489	0.367	0.393	0.444	0.389	0.403	0.384
P(W/D)	0.205	0.212	0.255	0.317	0.286	0.295	0.257	0.252	0.238	0.183	0.141	0.200
ALPHA	0.762	0.821	0.698	0.713	0.681	0.664	0.697	0.693	0.691	0.661	0.536	0.831
BETA	0.157	0.172	0.302	0.370	0.572	0.567	0.530	0.552	0.499	0.409	0.469	0.149
IA DUBUQUE												
P(W/W)	0.411	0.396	0.483	0.472	0.478	0.475	0.405	0.395	0.422	0.475	0.391	0.444
P(W/D)	0.234	0.212	0.269	0.326	0.301	0.286	0.298	0.219	0.237	0.184	0.173	0.248
ALPHA	0.722	0.804	0.814	0.802	0.733	0.752	0.673	0.752	0.644	0.746	0.595	0.744
BETA	0.227	0.201	0.344	0.484	0.558	0.564	0.674	0.680	0.795	0.528	0.633	0.266
KS DODGE CITY												
P(W/W)	0.287	0.305	0.397	0.402	0.484	0.492	0.421	0.441	0.442	0.425	0.411	0.384
P(W/D)	0.109	0.138	0.150	0.157	0.233	0.213	0.247	0.209	0.144	0.096	0.074	0.103
ALPHA	0.927	0.795	0.660	0.733	0.670	0.750	0.709	0.616	0.591	0.592	0.783	0.819
BETA	0.096	0.138	0.296	0.294	0.500	0.453	0.485	0.454	0.521	0.500	0.191	0.129
KS TOPEKA												
P(W/W)	0.336	0.301	0.480	0.471	0.460	0.471	0.442	0.381	0.419	0.419	0.388	0.342
P(W/D)	0.151	0.186	0.172	0.243	0.293	0.294	0.228	0.215	0.202	0.147	0.123	0.154
ALPHA	0.773	0.708	0.748	0.626	0.780	0.720	0.698	0.652	0.755	0.695	0.592	0.894
BETA	0.169	0.234	0.343	0.543	0.441	0.740	0.685	0.698	0.551	0.560	0.469	0.232

Table 10.1--Continued
Rainfall generation parameters for State and station by month

Variable	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
KS WICHITA												
P(W/W)	0.500	0.316	0.462	0.419	0.393	0.577	0.433	0.357	0.412	0.231	0.400	0.250
P(W/D)	0.060	0.212	0.194	0.322	0.246	0.188	0.254	0.292	0.123	0.137	0.157	0.111
ALPHA	0.621	0.734	0.524	0.551	0.690	0.786	0.640	0.989	0.724	0.998	0.609	0.858
BETA	0.256	0.256	0.666	0.503	0.640	0.628	0.634	0.304	0.639	0.416	0.461	0.232
KY COVINGTON												
P(W/W)	0.492	0.477	0.487	0.561	0.561	0.467	0.393	0.418	0.397	0.416	0.480	0.515
P(W/D)	0.326	0.332	0.380	0.343	0.265	0.259	0.283	0.211	0.198	0.197	0.289	0.309
ALPHA	0.655	0.708	0.603	0.696	0.794	0.672	0.763	0.648	0.797	0.719	0.680	0.684
BETA	0.405	0.378	0.501	0.388	0.411	0.527	0.589	0.459	0.420	0.400	0.403	0.356
KY LEXINGTON												
P(W/W)	0.496	0.489	0.502	0.520	0.500	0.526	0.430	0.394	0.441	0.400	0.459	0.478
P(W/D)	0.317	0.345	0.356	0.353	0.292	0.273	0.312	0.245	0.176	0.194	0.267	0.321
ALPHA	0.630	0.751	0.652	0.647	0.680	0.778	0.734	0.631	0.666	0.725	0.708	0.678
BETA	0.464	0.396	0.577	0.478	0.535	0.507	0.560	0.603	0.587	0.363	0.462	0.447
KY LOUISVILLE												
P(W/W)	0.472	0.466	0.484	0.512	0.547	0.513	0.449	0.379	0.420	0.383	0.439	0.486
P(W/D)	0.301	0.323	0.355	0.331	0.256	0.222	0.297	0.201	0.182	0.188	0.257	0.291
ALPHA	0.662	0.709	0.645	0.664	0.723	0.680	0.743	0.692	0.648	0.752	0.628	0.653
BETA	0.447	0.453	0.586	0.497	0.489	0.549	0.463	0.576	0.664	0.435	0.517	0.469
LA BATON ROUGE												
P(W/W)	0.381	0.466	0.398	0.376	0.506	0.531	0.560	0.452	0.416	0.376	0.305	0.464
P(W/D)	0.251	0.267	0.220	0.182	0.180	0.194	0.363	0.279	0.219	0.121	0.180	0.255
ALPHA	0.654	0.664	0.645	0.582	0.652	0.811	0.700	0.767	0.721	0.617	0.712	0.725
BETA	0.684	0.832	0.739	1.311	0.804	0.452	0.712	0.568	0.580	0.836	0.742	0.706
LA NEW ORLEANS												
P(W/W)	0.409	0.458	0.404	0.343	0.439	0.483	0.576	0.536	0.495	0.433	0.369	0.449
P(W/D)	0.253	0.279	0.227	0.197	0.191	0.258	0.368	0.329	0.237	0.130	0.168	0.274
ALPHA	0.575	0.615	0.570	0.604	0.660	0.691	0.705	0.642	0.646	0.694	0.593	0.633
BETA	0.865	0.903	0.871	0.935	0.870	0.641	0.684	0.670	0.846	0.571	0.825	0.803
LA SHREVEPORT												
P(W/W)	0.497	0.434	0.436	0.430	0.488	0.497	0.375	0.375	0.444	0.376	0.429	0.480
P(W/D)	0.221	0.237	0.248	0.245	0.186	0.154	0.187	0.163	0.163	0.131	0.205	0.222
ALPHA	0.625	0.699	0.729	0.665	0.668	0.578	0.607	0.527	0.663	0.713	0.652	0.645
BETA	0.599	0.621	0.514	0.875	0.834	0.868	0.637	0.759	0.740	0.583	0.692	0.704
ME CARIBOU												
P(W/W)	0.516	0.518	0.539	0.508	0.531	0.472	0.500	0.508	0.473	0.498	0.573	0.527
P(W/D)	0.409	0.368	0.315	0.318	0.332	0.376	0.424	0.367	0.361	0.316	0.389	0.379
ALPHA	0.779	0.826	0.756	0.808	0.858	0.782	0.719	0.682	0.609	0.676	0.788	0.720
BETA	0.192	0.217	0.227	0.264	0.248	0.318	0.385	0.438	0.487	0.400	0.304	0.280
ME PORTLAND												
P(W/W)	0.442	0.422	0.475	0.536	0.473	0.451	0.361	0.364	0.416	0.484	0.515	0.493
P(W/D)	0.295	0.341	0.281	0.310	0.321	0.310	0.261	0.299	0.234	0.229	0.308	0.299
ALPHA	0.765	0.672	0.716	0.717	0.714	0.651	0.724	0.708	0.631	0.603	0.691	0.670
BETA	0.413	0.540	0.490	0.421	0.370	0.423	0.402	0.384	0.597	0.614	0.605	0.566
MD BALTIMORE												
P(W/W)	0.446	0.441	0.504	0.502	0.447	0.392	0.333	0.458	0.421	0.365	0.414	0.407
P(W/D)	0.263	0.264	0.293	0.319	0.277	0.260	0.243	0.247	0.180	0.164	0.251	0.244
ALPHA	0.791	0.791	0.713	0.698	0.707	0.631	0.592	0.617	0.530	0.698	0.653	0.737
BETA	0.334	0.430	0.462	0.419	0.418	0.639	0.771	0.746	0.817	0.599	0.548	0.491

Table 10.1--Continued
Rainfall generation parameters for State and station by month

Variable	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
MA BOSTON												
P(W/W)	0.460	0.476	0.500	0.511	0.461	0.443	0.402	0.401	0.375	0.454	0.523	0.456
P(W/D)	0.333	0.359	0.315	0.302	0.313	0.305	0.248	0.286	0.252	0.229	0.307	0.294
ALPHA	0.689	0.618	0.662	0.720	0.670	0.680	0.663	0.582	0.562	0.607	0.601	0.679
BETA	0.456	0.564	0.558	0.474	0.469	0.427	0.448	0.637	0.709	0.596	0.653	0.640
MA NANTUCKET												
P(W/W)	0.498	0.443	0.445	0.483	0.412	0.355	0.316	0.397	0.461	0.448	0.527	0.500
P(W/D)	0.353	0.369	0.352	0.316	0.281	0.223	0.218	0.255	0.212	0.214	0.319	0.344
ALPHA	0.763	0.697	0.723	0.699	0.652	0.660	0.636	0.644	0.571	0.665	0.660	0.718
BETA	0.415	0.538	0.488	0.465	0.507	0.402	0.603	0.656	0.727	0.591	0.545	0.493
MI DETROIT												
P(W/W)	0.496	0.465	0.500	0.527	0.463	0.455	0.357	0.352	0.450	0.468	0.493	0.510
P(W/D)	0.351	0.329	0.335	0.332	0.313	0.289	0.241	0.225	0.221	0.180	0.262	0.351
ALPHA	0.695	0.775	0.772	0.741	0.684	0.776	0.713	0.704	0.778	0.672	0.743	0.651
BETA	0.211	0.203	0.231	0.339	0.345	0.388	0.475	0.528	0.335	0.440	0.289	0.261
MI GRAND RAPIDS												
P(W/W)	0.661	0.510	0.554	0.534	0.469	0.408	0.391	0.382	0.438	0.476	0.578	0.624
P(W/D)	0.362	0.392	0.352	0.333	0.278	0.288	0.252	0.218	0.276	0.230	0.295	0.373
ALPHA	0.802	0.788	0.762	0.772	0.706	0.699	0.756	0.757	0.646	0.673	0.727	0.805
BETA	0.153	0.157	0.228	0.373	0.379	0.514	0.438	0.462	0.508	0.451	0.322	0.173
MN DULUTH												
P(W/W)	0.528	0.463	0.474	0.498	0.546	0.506	0.439	0.444	0.509	0.524	0.559	0.574
P(W/D)	0.291	0.272	0.269	0.291	0.342	0.324	0.307	0.324	0.298	0.212	0.239	0.296
ALPHA	0.819	0.798	0.676	0.713	0.723	0.700	0.701	0.635	0.716	0.688	0.618	0.730
BETA	0.114	0.113	0.225	0.320	0.349	0.478	0.487	0.511	0.395	0.330	0.266	0.159
MN MINNEAPOLIS												
P(W/W)	0.416	0.414	0.419	0.407	0.502	0.496	0.361	0.383	0.455	0.431	0.407	0.447
P(W/D)	0.221	0.188	0.275	0.283	0.321	0.331	0.304	0.266	0.252	0.182	0.198	0.247
ALPHA	0.826	0.730	0.670	0.785	0.751	0.760	0.627	0.732	0.771	0.642	0.675	0.826
BETA	0.103	0.170	0.263	0.268	0.372	0.419	0.620	0.492	0.359	0.392	0.224	0.117
MS JACKSON												
P(W/W)	0.516	0.454	0.458	0.364	0.539	0.450	0.451	0.394	0.429	0.396	0.389	0.488
P(W/D)	0.262	0.287	0.258	0.267	0.170	0.205	0.289	0.246	0.174	0.126	0.217	0.267
ALPHA	0.636	0.758	0.670	0.657	0.684	0.673	0.759	0.623	0.540	0.551	0.652	0.679
BETA	0.605	0.573	0.720	0.840	0.775	0.598	0.516	0.630	0.843	0.749	0.661	0.725
MS MERIDIAN												
P(W/W)	0.411	0.441	0.414	0.399	0.434	0.412	0.456	0.402	0.429	0.436	0.317	0.439
P(W/D)	0.260	0.281	0.244	0.224	0.174	0.199	0.280	0.243	0.171	0.108	0.195	0.252
ALPHA	0.812	0.786	0.764	0.835	0.800	0.874	0.783	0.740	0.753	0.590	0.836	0.853
BETA	0.530	0.622	0.766	0.702	0.599	0.523	0.571	0.569	0.583	0.815	0.543	0.698
MO COLUMBIA												
P(W/W)	0.412	0.405	0.456	0.477	0.445	0.473	0.454	0.340	0.415	0.403	0.353	0.424
P(W/D)	0.181	0.224	0.274	0.309	0.279	0.279	0.243	0.205	0.199	0.182	0.163	0.208
ALPHA	0.643	0.712	0.695	0.816	0.803	0.677	0.706	0.662	0.612	0.585	0.735	0.750
BETA	0.315	0.318	0.359	0.374	0.503	0.596	0.605	0.565	0.805	0.745	0.368	0.275
MO KANSAS CITY												
P(W/W)	0.364	0.304	0.438	0.485	0.439	0.450	0.393	0.443	0.448	0.464	0.357	0.381
P(W/D)	0.157	0.216	0.215	0.260	0.305	0.284	0.235	0.203	0.214	0.156	0.135	0.166
ALPHA	0.727	0.713	0.682	0.754	0.687	0.786	0.672	0.646	0.662	0.695	0.553	0.859
BETA	0.259	0.288	0.440	0.454	0.580	0.654	0.783	0.736	0.780	0.633	0.521	0.238

Table 10.1--Continued
Rainfall generation parameters for State and station by month

Variable	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
MO ST. LOUIS												
P(W/W)	0.405	0.384	0.477	0.487	0.476	0.487	0.438	0.375	0.426	0.387	0.440	0.453
P(W/D)	0.195	0.254	0.276	0.328	0.273	0.243	0.224	0.201	0.190	0.184	0.193	0.218
ALPHA	0.753	0.670	0.725	0.814	0.716	0.664	0.674	0.735	0.796	0.813	0.692	0.753
BETA	0.281	0.392	0.363	0.392	0.473	0.642	0.623	0.437	0.434	0.417	0.431	0.306
MT BILLINGS												
P(W/W)	0.442	0.500	0.439	0.475	0.544	0.491	0.328	0.376	0.414	0.307	0.347	0.489
P(W/D)	0.198	0.184	0.241	0.233	0.270	0.314	0.177	0.170	0.165	0.160	0.166	0.139
ALPHA	0.998	0.998	0.845	0.775	0.740	0.728	0.662	0.743	0.753	0.768	0.732	0.911
BETA	0.094	0.095	0.130	0.267	0.261	0.290	0.189	0.218	0.241	0.191	0.181	0.111
MT GREAT FALLS												
P(W/W)	0.526	0.490	0.478	0.490	0.523	0.564	0.383	0.457	0.428	0.393	0.453	0.481
P(W/D)	0.210	0.211	0.207	0.245	0.269	0.297	0.177	0.162	0.169	0.129	0.156	0.178
ALPHA	0.923	0.913	0.998	0.738	0.675	0.692	0.818	0.731	0.787	0.914	0.899	0.988
BETA	0.113	0.111	0.104	0.193	0.339	0.356	0.201	0.223	0.184	0.151	0.132	0.092
MT HAVRE												
P(W/W)	0.503	0.481	0.317	0.449	0.457	0.500	0.433	0.424	0.433	0.273	0.394	0.453
P(W/D)	0.189	0.162	0.169	0.183	0.237	0.308	0.154	0.152	0.163	0.138	0.130	0.144
ALPHA	0.998	0.998	0.998	0.883	0.747	0.712	0.781	0.669	0.752	0.765	0.940	0.988
BETA	0.062	0.061	0.065	0.179	0.226	0.292	0.271	0.274	0.206	0.166	0.095	0.065
MT HELENA												
P(W/W)	0.429	0.328	0.421	0.373	0.498	0.573	0.381	0.361	0.446	0.331	0.390	0.481
P(W/D)	0.215	0.184	0.200	0.249	0.260	0.266	0.180	0.207	0.147	0.159	0.185	0.183
ALPHA	0.998	0.982	0.843	0.805	0.726	0.891	0.883	0.804	0.844	0.802	0.866	0.988
BETA	0.070	0.071	0.106	0.143	0.232	0.213	0.152	0.175	0.142	0.134	0.095	0.075
MT KALISPELL												
P(W/W)	0.658	0.567	0.539	0.429	0.518	0.563	0.310	0.510	0.525	0.540	0.525	0.570
P(W/D)	0.383	0.309	0.249	0.250	0.264	0.310	0.145	0.164	0.197	0.217	0.322	0.431
ALPHA	0.998	0.998	0.998	0.834	0.862	0.807	0.829	0.798	0.866	0.968	0.857	0.921
BETA	0.100	0.083	0.073	0.135	0.185	0.248	0.186	0.219	0.163	0.114	0.132	0.110
MT MILES CITY												
P(W/W)	0.444	0.467	0.385	0.488	0.507	0.491	0.344	0.386	0.460	0.324	0.355	0.497
P(W/D)	0.212	0.193	0.200	0.213	0.262	0.309	0.230	0.166	0.146	0.135	0.159	0.168
ALPHA	0.998	0.988	0.958	0.869	0.741	0.744	0.666	0.699	0.797	0.848	0.861	0.998
BETA	0.063	0.077	0.084	0.182	0.265	0.346	0.294	0.242	0.186	0.122	0.114	0.074
NE GRAND ISLAND												
P(W/W)	0.409	0.422	0.413	0.514	0.474	0.500	0.353	0.383	0.441	0.308	0.250	0.287
P(W/D)	0.108	0.181	0.178	0.204	0.278	0.259	0.271	0.221	0.188	0.113	0.109	0.120
ALPHA	0.841	0.795	0.745	0.645	0.724	0.745	0.668	0.647	0.650	0.885	0.780	0.676
BETA	0.120	0.155	0.224	0.441	0.478	0.546	0.476	0.501	0.471	0.263	0.159	0.202
NE NORTH PLATTE												
P(W/W)	0.292	0.377	0.344	0.448	0.498	0.453	0.377	0.314	0.435	0.351	0.309	0.268
P(W/D)	0.126	0.151	0.167	0.179	0.255	0.273	0.270	0.227	0.154	0.117	0.108	0.112
ALPHA	0.845	0.750	0.731	0.683	0.700	0.635	0.769	0.676	0.705	0.704	0.813	0.785
BETA	0.094	0.137	0.190	0.343	0.466	0.640	0.401	0.388	0.408	0.282	0.131	0.126
NE SCOTTSBLUFF												
P(W/W)	0.326	0.396	0.390	0.474	0.555	0.529	0.335	0.323	0.446	0.363	0.286	0.354
P(W/D)	0.122	0.133	0.192	0.189	0.269	0.312	0.240	0.171	0.147	0.112	0.112	0.129
ALPHA	0.998	0.998	0.877	0.858	0.715	0.699	0.676	0.789	0.600	0.720	0.868	0.998
BETA	0.069	0.065	0.114	0.196	0.343	0.398	0.334	0.184	0.279	0.233	0.100	0.084

Table 10.1--Continued
Rainfall generation parameters for State and station by month

Variable	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
NV ELKO												
P(W/W)	0.467	0.533	0.420	0.476	0.532	0.547	0.310	0.354	0.250	0.338	0.496	0.489
P(W/D)	0.224	0.216	0.212	0.163	0.176	0.130	0.095	0.091	0.083	0.080	0.146	0.220
ALPHA	0.797	0.928	0.958	0.905	0.960	0.809	0.828	0.565	0.779	0.738	0.998	0.921
BETA	0.164	0.091	0.108	0.115	0.117	0.189	0.114	0.310	0.131	0.193	0.124	0.134
NV LAS VEGAS												
P(W/W)	0.271	0.311	0.346	0.250	0.211	0.071	0.275	0.161	0.258	0.300	0.333	0.356
P(W/D)	0.061	0.065	0.055	0.048	0.025	0.022	0.067	0.082	0.040	0.041	0.056	0.047
ALPHA	0.808	0.921	0.802	0.749	0.727	0.669	0.672	0.543	0.629	0.799	0.605	0.826
BETA	0.200	0.125	0.149	0.182	0.157	0.245	0.263	0.240	0.313	0.155	0.380	0.162
NV RENO												
P(W/W)	0.496	0.454	0.380	0.349	0.414	0.386	0.294	0.420	0.297	0.250	0.500	0.484
P(W/D)	0.138	0.113	0.135	0.101	0.101	0.074	0.067	0.049	0.044	0.046	0.093	0.138
ALPHA	0.728	0.748	0.838	0.721	0.663	0.942	0.998	0.900	0.960	0.701	0.813	0.718
BETA	0.275	0.258	0.150	0.182	0.253	0.138	0.095	0.107	0.158	0.233	0.166	0.265
NV WINNEMUCCA												
P(W/W)	0.467	0.426	0.443	0.351	0.448	0.554	0.243	0.289	0.340	0.385	0.496	0.473
P(W/D)	0.198	0.177	0.153	0.146	0.147	0.113	0.053	0.052	0.058	0.087	0.149	0.193
ALPHA	0.928	0.961	0.998	0.786	0.899	0.718	0.787	0.759	0.783	0.761	0.998	0.930
BETA	0.123	0.115	0.094	0.172	0.138	0.224	0.106	0.192	0.142	0.179	0.123	0.119
NH CONCORD												
P(W/W)	0.405	0.396	0.459	0.441	0.463	0.457	0.368	0.403	0.409	0.422	0.494	0.461
P(W/D)	0.300	0.307	0.295	0.321	0.317	0.296	0.298	0.295	0.241	0.211	0.333	0.293
ALPHA	0.774	0.800	0.809	0.873	0.763	0.723	0.741	0.654	0.718	0.710	0.701	0.670
BETA	0.314	0.347	0.320	0.317	0.322	0.385	0.407	0.469	0.507	0.516	0.473	0.475
NH MT. WASHINGTON												
P(W/W)	0.648	0.673	0.724	0.710	0.632	0.628	0.616	0.638	0.634	0.646	0.726	0.714
P(W/D)	0.524	0.569	0.441	0.436	0.397	0.439	0.473	0.416	0.409	0.313	0.495	0.537
ALPHA	0.789	0.619	0.735	0.822	0.794	0.972	0.849	0.893	0.787	0.808	0.734	0.695
BETA	0.390	0.727	0.463	0.391	0.470	0.407	0.494	0.520	0.536	0.551	0.551	0.561
NJ NEWARK												
P(W/W)	0.437	0.398	0.470	0.463	0.473	0.407	0.448	0.432	0.426	0.378	0.450	0.461
P(W/D)	0.300	0.313	0.316	0.330	0.297	0.278	0.254	0.260	0.211	0.189	0.299	0.292
ALPHA	0.781	0.763	0.704	0.738	0.719	0.736	0.630	0.616	0.600	0.691	0.720	0.738
BETA	0.311	0.419	0.501	0.434	0.397	0.377	0.604	0.681	0.659	0.584	0.449	0.421
NM ALBUQUERQUE												
P(W/W)	0.263	0.392	0.346	0.264	0.346	0.412	0.395	0.429	0.320	0.378	0.339	0.350
P(W/D)	0.080	0.090	0.095	0.073	0.094	0.077	0.253	0.240	0.129	0.090	0.070	0.093
ALPHA	0.840	0.998	0.964	0.712	0.699	0.718	0.744	0.804	0.836	0.739	0.998	0.858
BETA	0.112	0.101	0.124	0.205	0.139	0.213	0.209	0.191	0.182	0.294	0.111	0.156
NM ROSWELL												
P(W/W)	0.314	0.352	0.358	0.286	0.329	0.307	0.408	0.421	0.384	0.531	0.360	0.359
P(W/D)	0.063	0.097	0.072	0.056	0.091	0.117	0.197	0.173	0.125	0.078	0.053	0.070
ALPHA	0.830	0.858	0.810	0.740	0.641	0.612	0.664	0.683	0.593	0.596	0.768	0.779
BETA	0.196	0.160	0.170	0.233	0.274	0.330	0.330	0.331	0.367	0.432	0.176	0.183
NY ALBANY												
P(W/W)	0.456	0.441	0.471	0.519	0.516	0.461	0.391	0.358	0.360	0.425	0.474	0.494
P(W/D)	0.360	0.365	0.331	0.331	0.336	0.310	0.303	0.322	0.254	0.210	0.340	0.339
ALPHA	0.755	0.683	0.747	0.708	0.673	0.741	0.695	0.705	0.672	0.709	0.788	0.673
BETA	0.232	0.294	0.323	0.333	0.372	0.337	0.386	0.399	0.556	0.462	0.312	0.358

Table 10.1--Continued
Rainfall generation parameters for State and station by month

Variable	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
NY BUFFALO												
P(W/W)	0.704	0.658	0.613	0.595	0.483	0.397	0.363	0.446	0.480	0.555	0.630	0.699
P(W/D)	0.578	0.485	0.421	0.409	0.339	0.276	0.283	0.300	0.270	0.239	0.412	0.533
ALPHA	0.779	0.728	0.752	0.783	0.757	0.785	0.719	0.754	0.728	0.711	0.824	0.751
BETA	0.188	0.203	0.236	0.270	0.316	0.307	0.419	0.461	0.407	0.374	0.287	0.205
NY NEW YORK												
P(W/W)	0.464	0.446	0.466	0.471	0.443	0.416	0.381	0.358	0.399	0.396	0.479	0.473
P(W/D)	0.302	0.296	0.325	0.354	0.314	0.271	0.245	0.297	0.217	0.191	0.283	0.299
ALPHA	0.739	0.671	0.683	0.650	0.664	0.765	0.627	0.583	0.667	0.608	0.683	0.658
BETA	0.328	0.492	0.509	0.494	0.413	0.380	0.628	0.768	0.579	0.682	0.514	0.481
NY SYRACUSE												
P(W/W)	0.655	0.657	0.631	0.583	0.510	0.413	0.445	0.399	0.467	0.532	0.608	0.674
P(W/D)	0.494	0.487	0.415	0.388	0.350	0.301	0.284	0.308	0.262	0.266	0.425	0.561
ALPHA	0.893	0.778	0.736	0.800	0.783	0.735	0.715	0.722	0.805	0.824	0.806	0.840
BETA	0.161	0.222	0.244	0.267	0.280	0.378	0.417	0.479	0.325	0.324	0.256	0.186
NC ASHEVILLE												
P(W/W)	0.448	0.507	0.519	0.520	0.535	0.498	0.551	0.542	0.532	0.582	0.450	0.492
P(W/D)	0.265	0.302	0.344	0.296	0.265	0.296	0.358	0.279	0.184	0.158	0.221	0.239
ALPHA	0.690	0.786	0.700	0.670	0.772	0.779	0.818	0.676	0.628	0.672	0.670	0.645
BETA	0.378	0.382	0.445	0.452	0.319	0.398	0.282	0.491	0.630	0.485	0.425	0.435
NC CHARLOTTE												
P(W/W)	0.463	0.498	0.515	0.465	0.472	0.371	0.495	0.490	0.345	0.523	0.361	0.395
P(W/D)	0.235	0.287	0.272	0.245	0.205	0.283	0.289	0.223	0.161	0.133	0.189	0.246
ALPHA	0.752	0.900	0.728	0.751	0.844	0.766	0.679	0.695	0.652	0.688	0.765	0.634
BETA	0.487	0.438	0.546	0.514	0.392	0.503	0.498	0.614	0.741	0.524	0.480	0.602
NC GREENSBORO												
P(W/W)	0.435	0.500	0.516	0.442	0.502	0.495	0.519	0.539	0.476	0.479	0.436	0.434
P(W/D)	0.255	0.281	0.264	0.279	0.232	0.266	0.301	0.244	0.167	0.158	0.199	0.202
ALPHA	0.739	0.819	0.803	0.725	0.721	0.646	0.694	0.643	0.535	0.562	0.697	0.713
BETA	0.459	0.437	0.426	0.465	0.389	0.628	0.500	0.647	0.768	0.769	0.450	0.581
NC RALEIGH												
P(W/W)	0.416	0.508	0.465	0.433	0.442	0.459	0.521	0.480	0.431	0.400	0.418	0.425
P(W/D)	0.251	0.258	0.261	0.247	0.247	0.236	0.264	0.243	0.147	0.150	0.201	0.204
ALPHA	0.722	0.808	0.873	0.844	0.797	0.732	0.770	0.620	0.729	0.722	0.755	0.850
BETA	0.485	0.454	0.390	0.405	0.428	0.541	0.571	0.813	0.643	0.592	0.473	0.434
ND BISMARCK												
P(W/W)	0.354	0.393	0.372	0.477	0.480	0.519	0.412	0.330	0.344	0.363	0.445	0.437
P(W/D)	0.227	0.188	0.205	0.187	0.261	0.328	0.249	0.277	0.200	0.112	0.139	0.197
ALPHA	0.998	0.935	0.803	0.704	0.698	0.673	0.690	0.626	0.755	0.822	0.828	0.998
BETA	0.066	0.074	0.100	0.250	0.328	0.422	0.336	0.321	0.226	0.158	0.108	0.062
ND WILLISTON												
P(W/W)	0.409	0.374	0.349	0.397	0.469	0.480	0.396	0.297	0.383	0.364	0.393	0.469
P(W/D)	0.227	0.204	0.206	0.187	0.189	0.322	0.240	0.205	0.176	0.119	0.155	0.169
ALPHA	0.998	0.998	0.998	0.731	0.728	0.689	0.644	0.644	0.664	0.733	0.998	0.998
BETA	0.071	0.077	0.065	0.251	0.287	0.360	0.345	0.326	0.274	0.179	0.081	0.067
OH CLEVELAND												
P(W/W)	0.598	0.606	0.583	0.584	0.506	0.438	0.395	0.384	0.429	0.505	0.613	0.626
P(W/D)	0.470	0.452	0.432	0.404	0.319	0.290	0.292	0.267	0.252	0.244	0.352	0.419
ALPHA	0.702	0.781	0.780	0.811	0.794	0.769	0.639	0.691	0.823	0.775	0.748	0.762
BETA	0.219	0.179	0.235	0.302	0.331	0.379	0.520	0.455	0.348	0.324	0.267	0.197

Table 10.1--Continued
Rainfall generation parameters for State and station by month

Variable	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
OH COLUMBUS												
P(W/W)	0.504	0.480	0.516	0.545	0.500	0.463	0.391	0.350	0.418	0.423	0.509	0.502
P(W/D)	0.339	0.359	0.384	0.360	0.328	0.276	0.323	0.230	0.216	0.205	0.288	0.329
ALPHA	0.683	0.757	0.664	0.788	0.754	0.733	0.720	0.822	0.766	0.879	0.740	0.739
BETA	0.325	0.263	0.359	0.358	0.423	0.489	0.543	0.419	0.377	0.252	0.309	0.267
OH TOLEDO												
P(W/W)	0.534	0.450	0.515	0.520	0.519	0.459	0.392	0.364	0.433	0.431	0.505	0.521
P(W/D)	0.350	0.326	0.364	0.366	0.287	0.252	0.260	0.229	0.251	0.186	0.279	0.363
ALPHA	0.656	0.752	0.724	0.745	0.802	0.763	0.716	0.737	0.755	0.674	0.759	0.640
BETA	0.240	0.228	0.251	0.305	0.313	0.434	0.504	0.508	0.321	0.381	0.287	0.283
OK OKLAHOMA CITY												
P(W/W)	0.370	0.415	0.450	0.399	0.492	0.447	0.407	0.328	0.360	0.374	0.424	0.396
P(W/D)	0.123	0.172	0.179	0.197	0.217	0.205	0.175	0.190	0.190	0.117	0.100	0.125
ALPHA	0.703	0.744	0.669	0.660	0.632	0.664	0.707	0.696	0.608	0.638	0.616	0.644
BETA	0.247	0.255	0.387	0.638	0.873	0.696	0.572	0.551	0.880	0.867	0.529	0.351
OK TULSA												
P(W/W)	0.404	0.438	0.414	0.461	0.483	0.413	0.422	0.326	0.399	0.427	0.392	0.422
P(W/D)	0.146	0.184	0.205	0.231	0.260	0.217	0.186	0.171	0.193	0.133	0.146	0.165
ALPHA	0.711	0.757	0.672	0.707	0.658	0.647	0.591	0.662	0.638	0.582	0.605	0.625
BETA	0.301	0.307	0.494	0.630	0.662	0.757	0.909	0.662	0.816	0.912	0.547	0.382
OR BURNS												
P(W/W)	0.566	0.519	0.545	0.438	0.468	0.433	0.255	0.352	0.339	0.508	0.596	0.606
P(W/D)	0.353	0.223	0.233	0.178	0.180	0.157	0.067	0.082	0.072	0.127	0.201	0.243
ALPHA	0.910	0.890	0.998	0.927	0.986	0.930	0.868	0.792	0.657	0.738	0.998	0.897
BETA	0.152	0.142	0.096	0.107	0.126	0.139	0.148	0.164	0.263	0.203	0.146	0.168
OR MEACHUM												
P(W/W)	0.737	0.729	0.713	0.663	0.610	0.556	0.299	0.536	0.521	0.633	0.721	0.716
P(W/D)	0.484	0.331	0.311	0.291	0.270	0.216	0.080	0.100	0.129	0.194	0.298	0.371
ALPHA	0.844	0.900	0.998	0.919	0.920	0.838	0.816	0.688	0.792	0.801	0.927	0.906
BETA	0.279	0.232	0.184	0.210	0.192	0.224	0.172	0.269	0.304	0.307	0.272	0.281
OR MEDFORD												
P(W/W)	0.655	0.557	0.588	0.534	0.538	0.452	0.344	0.367	0.318	0.529	0.627	0.657
P(W/D)	0.361	0.269	0.236	0.189	0.174	0.111	0.036	0.053	0.086	0.159	0.273	0.281
ALPHA	0.703	0.608	0.876	0.946	0.791	0.985	0.579	0.998	0.724	0.678	0.692	0.654
BETA	0.346	0.344	0.174	0.111	0.190	0.138	0.296	0.153	0.248	0.337	0.345	0.422
OR PENDLETON												
P(W/W)	0.571	0.535	0.485	0.434	0.452	0.364	0.232	0.391	0.383	0.462	0.521	0.551
P(W/D)	0.353	0.247	0.250	0.249	0.179	0.163	0.067	0.078	0.108	0.174	0.275	0.369
ALPHA	0.966	0.977	0.998	0.938	0.874	0.843	0.957	0.932	0.913	0.813	0.933	0.909
BETA	0.134	0.111	0.100	0.108	0.163	0.145	0.096	0.111	0.149	0.156	0.139	0.119
OR PORTLAND												
P(W/W)	0.802	0.697	0.726	0.634	0.619	0.561	0.386	0.585	0.497	0.684	0.775	0.752
P(W/D)	0.425	0.357	0.344	0.309	0.236	0.188	0.071	0.082	0.172	0.232	0.324	0.443
ALPHA	0.830	0.840	0.998	0.945	0.853	0.854	0.788	0.843	0.790	0.962	0.869	0.879
BETA	0.369	0.303	0.211	0.177	0.196	0.207	0.144	0.224	0.239	0.269	0.343	0.352
OR SALEM												
P(W/W)	0.791	0.728	0.750	0.638	0.611	0.555	0.404	0.494	0.507	0.659	0.776	0.775
P(W/D)	0.411	0.341	0.293	0.304	0.215	0.151	0.045	0.086	0.148	0.233	0.339	0.427
ALPHA	0.866	0.763	0.964	0.867	0.998	0.776	0.826	0.829	0.722	0.866	0.833	0.827
BETA	0.435	0.380	0.270	0.198	0.172	0.221	0.148	0.157	0.296	0.337	0.380	0.434

Table 10.1--Continued
Rainfall generation parameters for State and station by month

Variable	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
OR SEXTON SUMMIT												
P(W/W)	0.774	0.689	0.712	0.604	0.602	0.476	0.212	0.426	0.489	0.632	0.719	0.745
P(W/D)	0.373	0.312	0.310	0.230	0.179	0.126	0.044	0.053	0.101	0.174	0.276	0.286
ALPHA	0.730	0.712	0.887	0.835	0.776	0.890	0.819	0.749	0.745	0.729	0.649	0.731
BETA	0.533	0.429	0.262	0.223	0.277	0.191	0.173	0.264	0.305	0.445	0.577	0.559
PA PHILADELPHIA												
P(W/W)	0.464	0.393	0.438	0.459	0.437	0.395	0.372	0.421	0.407	0.381	0.441	0.478
P(W/D)	0.268	0.295	0.298	0.313	0.275	0.272	0.246	0.256	0.185	0.171	0.257	0.255
ALPHA	0.749	0.757	0.811	0.759	0.760	0.585	0.664	0.668	0.613	0.577	0.735	0.673
BETA	0.342	0.388	0.442	0.405	0.365	0.684	0.665	0.615	0.746	0.678	0.467	0.502
PA PITTSBURGH												
P(W/W)	0.596	0.606	0.582	0.526	0.516	0.486	0.400	0.360	0.391	0.443	0.565	0.608
P(W/D)	0.443	0.414	0.451	0.393	0.311	0.304	0.317	0.267	0.219	0.255	0.328	0.451
ALPHA	0.751	0.836	0.731	0.847	0.772	0.733	0.728	0.651	0.723	0.695	0.841	0.765
BETA	0.225	0.197	0.303	0.312	0.369	0.429	0.465	0.530	0.402	0.357	0.215	0.188
RI PROVIDENCE												
P(W/W)	0.422	0.461	0.453	0.484	0.445	0.465	0.354	0.372	0.400	0.405	0.495	0.450
P(W/D)	0.336	0.323	0.321	0.298	0.301	0.297	0.256	0.304	0.211	0.208	0.292	0.329
ALPHA	0.650	0.637	0.657	0.658	0.670	0.650	0.655	0.589	0.636	0.590	0.626	0.645
BETA	0.477	0.568	0.562	0.549	0.451	0.371	0.491	0.640	0.683	0.735	0.633	0.592
SC CHARLESTON												
P(W/W)	0.438	0.448	0.478	0.377	0.443	0.569	0.539	0.520	0.481	0.472	0.383	0.404
P(W/D)	0.244	0.268	0.265	0.194	0.205	0.259	0.381	0.310	0.231	0.134	0.171	0.222
ALPHA	0.702	0.760	0.707	0.710	0.628	0.603	0.710	0.677	0.758	0.576	0.657	0.678
BETA	0.478	0.506	0.604	0.551	0.749	0.941	0.840	0.753	0.684	0.894	0.437	0.501
SC COLUMBIA												
P(W/W)	0.492	0.477	0.481	0.449	0.417	0.446	0.515	0.502	0.462	0.529	0.392	0.416
P(W/D)	0.227	0.283	0.262	0.227	0.206	0.246	0.290	0.260	0.162	0.112	0.168	0.229
ALPHA	0.649	0.731	0.758	0.674	0.758	0.812	0.672	0.637	0.559	0.578	0.723	0.737
BETA	0.612	0.559	0.593	0.634	0.581	0.475	0.676	0.837	1.031	0.824	0.473	0.507
SD HURON												
P(W/W)	0.333	0.445	0.379	0.457	0.485	0.465	0.358	0.360	0.368	0.433	0.368	0.331
P(W/D)	0.171	0.167	0.189	0.252	0.263	0.324	0.261	0.254	0.176	0.114	0.134	0.169
ALPHA	0.998	0.707	0.712	0.682	0.616	0.652	0.664	0.615	0.705	0.611	0.699	0.761
BETA	0.055	0.181	0.185	0.300	0.426	0.514	0.388	0.391	0.322	0.419	0.175	0.127
SD RAPID CITY												
P(W/W)	0.370	0.503	0.444	0.518	0.519	0.557	0.394	0.338	0.362	0.360	0.382	0.411
P(W/D)	0.156	0.200	0.222	0.233	0.306	0.317	0.239	0.208	0.167	0.103	0.157	0.155
ALPHA	0.998	0.988	0.815	0.776	0.674	0.713	0.622	0.757	0.708	0.782	0.830	0.998
BETA	0.064	0.088	0.130	0.263	0.346	0.378	0.390	0.251	0.250	0.201	0.098	0.070
TN CHATTONOOGA												
P(W/W)	0.513	0.517	0.489	0.493	0.473	0.465	0.541	0.457	0.443	0.489	0.453	0.453
P(W/D)	0.268	0.295	0.289	0.270	0.228	0.264	0.263	0.240	0.201	0.154	0.217	0.263
ALPHA	0.727	0.769	0.671	0.719	0.794	0.721	0.801	0.679	0.632	0.738	0.784	0.718
BETA	0.623	0.612	0.725	0.635	0.457	0.464	0.481	0.502	0.732	0.519	0.572	0.733
TN KNOXVILLE												
P(W/W)	0.506	0.531	0.506	0.528	0.473	0.444	0.494	0.422	0.477	0.503	0.467	0.466
P(W/D)	0.317	0.329	0.327	0.294	0.253	0.291	0.304	0.257	0.191	0.170	0.271	0.289
ALPHA	0.747	0.774	0.737	0.759	0.916	0.720	0.778	0.681	0.732	0.729	0.731	0.664
BETA	0.489	0.517	0.550	0.442	0.336	0.528	0.452	0.493	0.478	0.439	0.490	0.644

Table 10.1--Continued
Rainfall generation parameters for State and station by month

Variable	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
TN MEMPHIS												
P(W/W)	0.472	0.455	0.491	0.431	0.482	0.469	0.395	0.397	0.424	0.324	0.374	0.439
P(W/D)	0.246	0.294	0.270	0.295	0.184	0.200	0.241	0.205	0.154	0.146	0.222	0.259
ALPHA	0.645	0.753	0.755	0.729	0.717	0.755	0.698	0.620	0.658	0.657	0.715	0.686
BETA	0.713	0.619	0.605	0.784	0.806	0.535	0.652	0.763	0.777	0.595	0.604	0.684
TN NASHVILLE												
P(W/W)	0.484	0.521	0.500	0.476	0.485	0.516	0.422	0.386	0.462	0.408	0.399	0.493
P(W/D)	0.274	0.299	0.280	0.323	0.248	0.238	0.272	0.214	0.174	0.161	0.249	0.280
ALPHA	0.655	0.835	0.705	0.763	0.743	0.718	0.705	0.751	0.647	0.738	0.805	0.721
BETA	0.616	0.488	0.652	0.512	0.553	0.533	0.524	0.489	0.679	0.456	0.438	0.568
TX ABELENE												
P(W/W)	0.333	0.402	0.318	0.453	0.459	0.491	0.357	0.303	0.415	0.337	0.388	0.392
P(W/D)	0.102	0.135	0.111	0.149	0.179	0.115	0.097	0.136	0.149	0.136	0.116	0.089
ALPHA	0.603	0.796	0.864	0.741	0.676	0.633	0.637	0.587	0.609	0.611	0.707	0.700
BETA	0.425	0.249	0.241	0.565	0.730	0.811	0.858	0.675	0.707	0.663	0.436	0.295
TX AMARILLO												
P(W/W)	0.313	0.353	0.326	0.376	0.443	0.448	0.464	0.373	0.303	0.477	0.419	0.365
P(W/D)	0.081	0.117	0.121	0.107	0.212	0.207	0.203	0.203	0.147	0.090	0.061	0.092
ALPHA	0.654	0.748	0.748	0.687	0.575	0.582	0.615	0.639	0.572	0.664	0.834	0.645
BETA	0.214	0.173	0.240	0.352	0.560	0.753	0.546	0.560	0.564	0.479	0.214	0.237
TX AUSTIN												
P(W/W)	0.444	0.479	0.393	0.397	0.418	0.478	0.312	0.430	0.445	0.390	0.438	0.479
P(W/D)	0.174	0.205	0.179	0.190	0.197	0.117	0.101	0.115	0.172	0.143	0.146	0.144
ALPHA	0.601	0.555	0.632	0.613	0.571	0.611	0.547	0.643	0.637	0.550	0.593	0.556
BETA	0.366	0.644	0.368	0.688	0.841	0.993	0.701	0.653	0.805	1.048	0.534	0.554
TX BROWNSVILLE												
P(W/W)	0.459	0.485	0.413	0.380	0.433	0.527	0.387	0.484	0.540	0.420	0.440	0.492
P(W/D)	0.148	0.158	0.097	0.087	0.094	0.107	0.093	0.138	0.226	0.160	0.138	0.134
ALPHA	0.614	0.469	0.646	0.517	0.535	0.586	0.615	0.628	0.579	0.507	0.623	0.559
BETA	0.324	0.529	0.205	0.636	0.978	0.698	0.382	0.601	0.904	1.074	0.382	0.311
TX CORPUS CHRISTI												
P(W/W)	0.456	0.482	0.327	0.309	0.408	0.422	0.371	0.448	0.529	0.438	0.438	0.431
P(W/D)	0.171	0.165	0.138	0.130	0.153	0.130	0.104	0.113	0.219	0.142	0.136	0.141
ALPHA	0.483	0.547	0.635	0.453	0.581	0.560	0.562	0.597	0.565	0.553	0.636	0.544
BETA	0.435	0.484	0.238	0.882	0.775	0.961	0.585	0.991	1.029	0.862	0.419	0.459
TX DALLAS												
P(W/W)	0.431	0.456	0.404	0.471	0.447	0.392	0.348	0.298	0.440	0.320	0.447	0.435
P(W/D)	0.153	0.195	0.203	0.196	0.202	0.146	0.105	0.139	0.143	0.126	0.134	0.131
ALPHA	0.750	0.653	0.612	0.673	0.632	0.713	0.568	0.581	0.667	0.525	0.652	0.661
BETA	0.358	0.448	0.586	0.924	0.824	0.659	0.703	0.655	0.882	1.281	0.704	0.589
TX EL PASO												
P(W/W)	0.368	0.352	0.288	0.235	0.257	0.250	0.320	0.441	0.376	0.328	0.320	0.368
P(W/D)	0.060	0.067	0.075	0.046	0.043	0.087	0.229	0.168	0.093	0.077	0.064	0.080
ALPHA	0.988	0.911	0.817	0.658	0.709	0.694	0.645	0.716	0.558	0.827	0.890	0.976
BETA	0.107	0.179	0.165	0.188	0.208	0.279	0.338	0.222	0.510	0.214	0.146	0.117
TX GALVESTON												
P(W/W)	0.383	0.436	0.341	0.311	0.407	0.468	0.453	0.462	0.574	0.424	0.425	0.436
P(W/D)	0.232	0.251	0.186	0.172	0.141	0.141	0.162	0.206	0.175	0.131	0.156	0.221
ALPHA	0.640	0.622	0.567	0.551	0.589	0.580	0.609	0.635	0.523	0.727	0.613	0.691
BETA	0.509	0.566	0.513	0.806	0.838	1.029	0.853	0.805	1.357	0.629	0.718	0.651

Table 10.1--Continued
Rainfall generation parameters for State and station by month

Variable	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
TX HOUSTON												
P(W/W)	0.407	0.492	0.369	0.410	0.440	0.478	0.443	0.464	0.541	0.508	0.410	0.473
P(W/D)	0.253	0.237	0.218	0.212	0.189	0.156	0.214	0.219	0.186	0.135	0.205	0.232
ALPHA	0.558	0.564	0.507	0.485	0.565	0.585	0.594	0.581	0.645	0.545	0.584	0.626
BETA	0.615	0.754	0.574	0.899	1.085	1.112	0.710	0.747	0.843	1.034	0.774	0.663
TX SAN ANTONIO												
P(W/W)	0.446	0.494	0.409	0.387	0.403	0.417	0.319	0.378	0.486	0.445	0.448	0.432
P(W/D)	0.180	0.195	0.166	0.179	0.195	0.123	0.088	0.115	0.167	0.135	0.140	0.158
ALPHA	0.521	0.604	0.502	0.545	0.592	0.562	0.495	0.566	0.689	0.600	0.577	0.606
BETA	0.392	0.453	0.420	0.584	0.719	0.947	0.841	0.769	0.650	0.762	0.593	0.343
TX TEMPLE												
P(W/W)	0.507	0.451	0.399	0.477	0.448	0.407	0.333	0.365	0.448	0.421	0.547	0.482
P(W/D)	0.149	0.213	0.176	0.178	0.193	0.133	0.079	0.118	0.161	0.125	0.127	0.151
ALPHA	0.659	0.735	0.713	0.680	0.630	0.704	0.705	0.584	0.686	0.488	0.633	0.590
BETA	0.428	0.454	0.360	0.663	0.816	0.677	0.593	0.831	0.695	1.308	0.616	0.563
TX WACO												
P(W/W)	0.397	0.424	0.417	0.414	0.429	0.416	0.344	0.389	0.455	0.337	0.425	0.414
P(W/D)	0.148	0.210	0.166	0.203	0.188	0.138	0.072	0.111	0.138	0.123	0.142	0.133
ALPHA	0.650	0.744	0.676	0.573	0.612	0.651	0.639	0.711	0.706	0.626	0.707	0.677
BETA	0.415	0.387	0.446	0.838	1.014	0.699	0.493	0.546	0.776	0.858	0.580	0.470
UT MILFORD												
P(W/W)	0.364	0.400	0.497	0.442	0.412	0.403	0.344	0.392	0.313	0.408	0.364	0.441
P(W/D)	0.151	0.200	0.156	0.153	0.099	0.079	0.119	0.147	0.100	0.078	0.111	0.131
ALPHA	0.863	0.990	0.981	0.920	0.998	0.770	0.771	0.890	0.721	0.848	0.889	0.956
BETA	0.122	0.105	0.133	0.159	0.133	0.185	0.154	0.112	0.267	0.175	0.169	0.112
UT SALT LAKE CITY												
P(W/W)	0.479	0.397	0.463	0.525	0.487	0.500	0.315	0.373	0.389	0.461	0.434	0.497
P(W/D)	0.226	0.263	0.236	0.239	0.165	0.139	0.104	0.139	0.111	0.108	0.170	0.230
ALPHA	0.854	0.881	0.911	0.799	0.853	0.734	0.635	0.638	0.696	0.702	0.821	0.879
BETA	0.165	0.169	0.178	0.276	0.206	0.249	0.299	0.264	0.219	0.265	0.212	0.170
VA NORFOLK												
P(W/W)	0.477	0.470	0.429	0.442	0.445	0.435	0.535	0.484	0.478	0.453	0.412	0.405
P(W/D)	0.246	0.289	0.316	0.301	0.242	0.228	0.266	0.272	0.184	0.174	0.223	0.226
ALPHA	0.728	0.757	0.744	0.782	0.727	0.645	0.704	0.608	0.519	0.619	0.666	0.823
BETA	0.493	0.446	0.426	0.331	0.477	0.617	0.647	0.934	1.044	0.713	0.508	0.452
VA RICHMOND												
P(W/W)	0.474	0.446	0.460	0.477	0.490	0.472	0.448	0.472	0.424	0.382	0.396	0.402
P(W/D)	0.252	0.266	0.284	0.253	0.243	0.226	0.271	0.249	0.187	0.172	0.237	0.215
ALPHA	0.770	0.843	0.816	0.825	0.734	0.646	0.642	0.607	0.642	0.623	0.620	0.751
BETA	0.374	0.431	0.393	0.353	0.419	0.641	0.802	0.881	0.661	0.743	0.642	0.553
WA OLYMPIA												
P(W/W)	0.816	0.766	0.758	0.698	0.586	0.542	0.489	0.571	0.601	0.707	0.787	0.788
P(W/D)	0.452	0.344	0.321	0.276	0.185	0.194	0.079	0.106	0.160	0.267	0.349	0.455
ALPHA	0.848	0.862	0.998	0.917	0.998	0.796	0.998	0.753	0.848	0.863	0.800	0.851
BETA	0.482	0.392	0.264	0.236	0.171	0.194	0.149	0.262	0.289	0.419	0.530	0.462
WA SPOKANE												
P(W/W)	0.648	0.600	0.542	0.409	0.469	0.400	0.240	0.388	0.395	0.479	0.584	0.621
P(W/D)	0.361	0.269	0.239	0.225	0.202	0.200	0.099	0.121	0.154	0.184	0.278	0.386
ALPHA	0.955	0.998	0.956	0.933	0.889	0.702	0.878	0.746	0.824	0.910	0.903	0.887
BETA	0.181	0.143	0.139	0.135	0.161	0.242	0.131	0.173	0.135	0.168	0.199	0.178

Table 10.1--Continued
Rainfall generation parameters for State and station by month

Variable	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
WA STAMPEDE PASS												
P(W/W)	0.867	0.822	0.807	0.774	0.684	0.714	0.530	0.649	0.638	0.723	0.807	0.858
P(W/D)	0.457	0.418	0.388	0.379	0.323	0.284	0.161	0.209	0.251	0.330	0.361	0.442
ALPHA	0.858	0.772	0.889	0.809	0.846	0.785	0.822	0.775	0.701	0.874	0.824	0.797
BETA	0.698	0.680	0.486	0.458	0.285	0.307	0.217	0.282	0.543	0.596	0.763	0.775
WA WALLA WALLA												
P(W/W)	0.592	0.560	0.486	0.457	0.451	0.336	0.306	0.328	0.415	0.454	0.539	0.548
P(W/D)	0.377	0.262	0.259	0.240	0.197	0.181	0.054	0.085	0.119	0.200	0.304	0.370
ALPHA	0.878	0.880	0.897	0.878	0.766	0.780	0.671	0.778	0.860	0.702	0.855	0.822
BETA	0.174	0.146	0.148	0.167	0.229	0.197	0.208	0.201	0.196	0.235	0.180	0.174
WA YAKIMA												
P(W/W)	0.553	0.574	0.423	0.360	0.337	0.290	0.182	0.296	0.245	0.368	0.470	0.493
P(W/D)	0.229	0.126	0.126	0.110	0.126	0.124	0.044	0.069	0.073	0.114	0.188	0.229
ALPHA	0.811	0.873	0.998	0.988	0.977	0.807	0.902	0.998	0.872	0.878	0.974	0.809
BETA	0.175	0.134	0.118	0.119	0.105	0.177	0.106	0.093	0.127	0.117	0.131	0.161
WV CHARLESTON												
P(W/W)	0.541	0.551	0.577	0.548	0.550	0.500	0.466	0.473	0.473	0.464	0.514	0.521
P(W/D)	0.383	0.395	0.397	0.395	0.314	0.264	0.369	0.249	0.213	0.222	0.279	0.384
ALPHA	0.741	0.730	0.761	0.828	0.747	0.827	0.680	0.683	0.780	0.693	0.850	0.746
BETA	0.315	0.344	0.364	0.304	0.365	0.351	0.598	0.547	0.398	0.380	0.289	0.300
WI GREEN BAY												
P(W/W)	0.400	0.393	0.495	0.493	0.471	0.487	0.398	0.405	0.426	0.467	0.425	0.420
P(W/D)	0.282	0.217	0.262	0.271	0.339	0.298	0.273	0.267	0.293	0.196	0.223	0.286
ALPHA	0.821	0.822	0.808	0.781	0.718	0.734	0.688	0.787	0.728	0.724	0.754	0.825
BETA	0.130	0.159	0.180	0.346	0.362	0.407	0.509	0.342	0.454	0.365	0.252	0.150
WI LA CROSSE												
P(W/W)	0.320	0.410	0.425	0.406	0.515	0.448	0.359	0.412	0.465	0.403	0.414	0.413
P(W/D)	0.233	0.161	0.272	0.274	0.296	0.308	0.287	0.245	0.242	0.204	0.178	0.221
ALPHA	0.838	0.778	0.723	0.791	0.862	0.728	0.732	0.816	0.722	0.793	0.662	0.874
BETA	0.127	0.158	0.264	0.362	0.356	0.554	0.555	0.437	0.516	0.345	0.310	0.131
WI MADISON												
P(W/W)	0.392	0.409	0.468	0.487	0.522	0.452	0.380	0.369	0.432	0.471	0.419	0.455
P(W/D)	0.284	0.204	0.292	0.322	0.287	0.297	0.282	0.256	0.245	0.204	0.219	0.218
ALPHA	0.794	0.751	0.783	0.709	0.713	0.695	0.655	0.689	0.631	0.688	0.654	0.767
BETA	0.137	0.170	0.220	0.350	0.408	0.568	0.616	0.544	0.549	0.413	0.329	0.214
WI MILWAUKEE												
P(W/W)	0.481	0.449	0.466	0.506	0.463	0.509	0.398	0.410	0.464	0.475	0.414	0.466
P(W/D)	0.288	0.260	0.299	0.349	0.313	0.285	0.288	0.226	0.240	0.206	0.243	0.269
ALPHA	0.661	0.756	0.711	0.759	0.800	0.670	0.635	0.650	0.638	0.670	0.692	0.695
BETA	0.208	0.167	0.281	0.323	0.297	0.486	0.584	0.525	0.472	0.390	0.323	0.239
WY CHEYENNE												
P(W/W)	0.360	0.414	0.489	0.527	0.597	0.488	0.425	0.373	0.444	0.386	0.398	0.343
P(W/D)	0.125	0.176	0.225	0.206	0.251	0.282	0.293	0.255	0.159	0.123	0.133	0.131
ALPHA	0.998	0.924	0.833	0.864	0.749	0.689	0.742	0.737	0.735	0.794	0.942	0.967
BETA	0.064	0.071	0.117	0.159	0.283	0.302	0.219	0.222	0.214	0.191	0.091	0.065

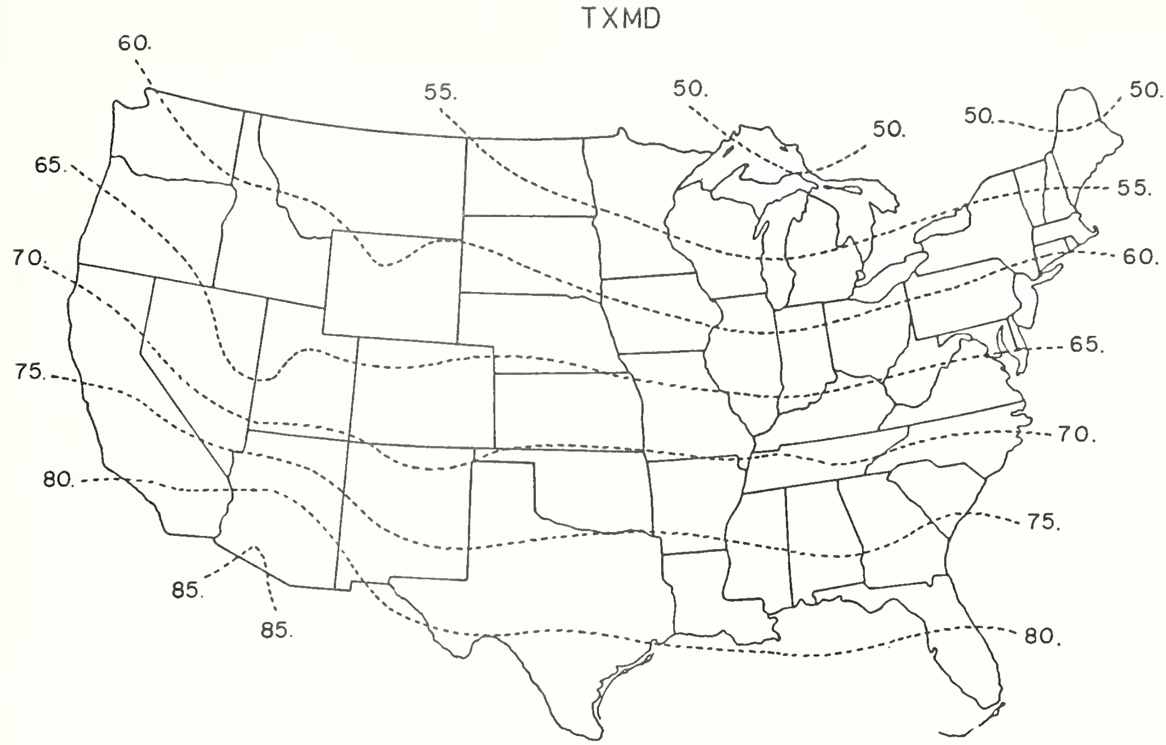

Figure 10.1
Distribution of TXMD within the contiguous United States.

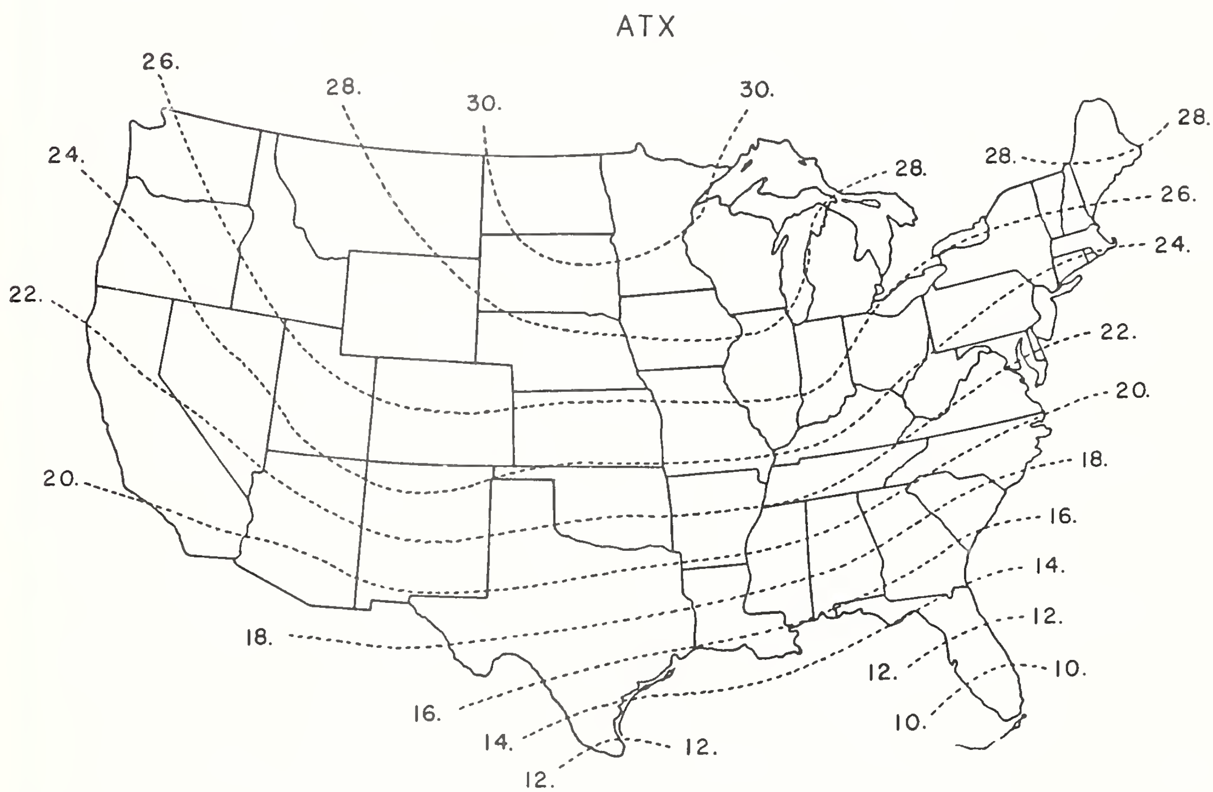

Figure 10.2
Distribution of ATX within the contiguous United States.

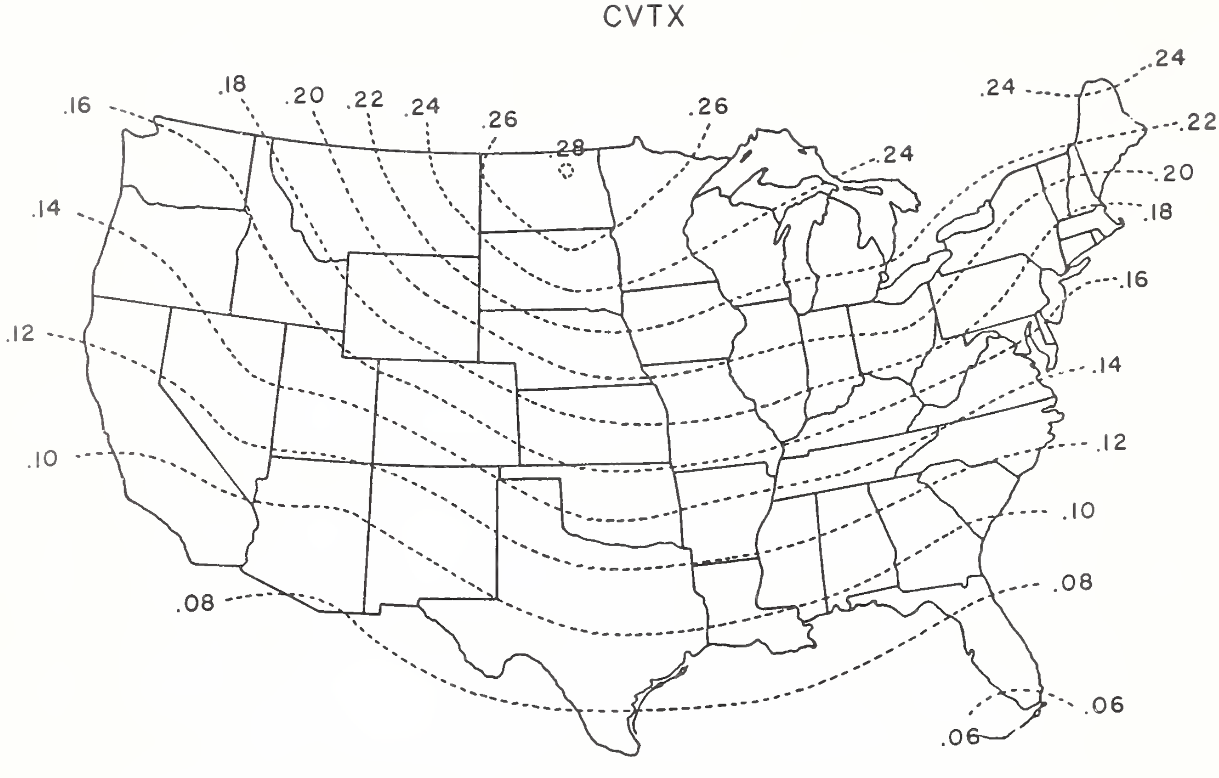

Figure 10.3
Distribution of CVTX within the contiguous United States.

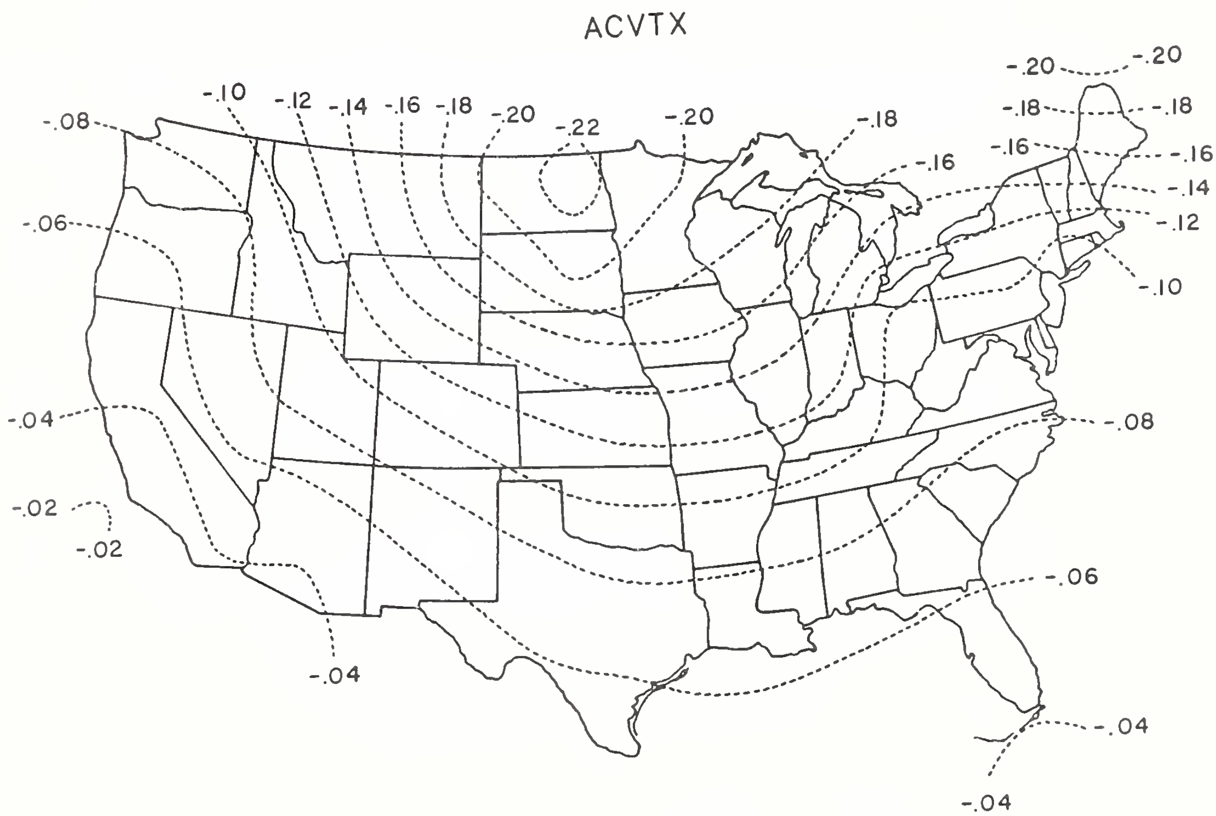

Figure 10.4
Distribution of ACVTX within the contiguous United States.

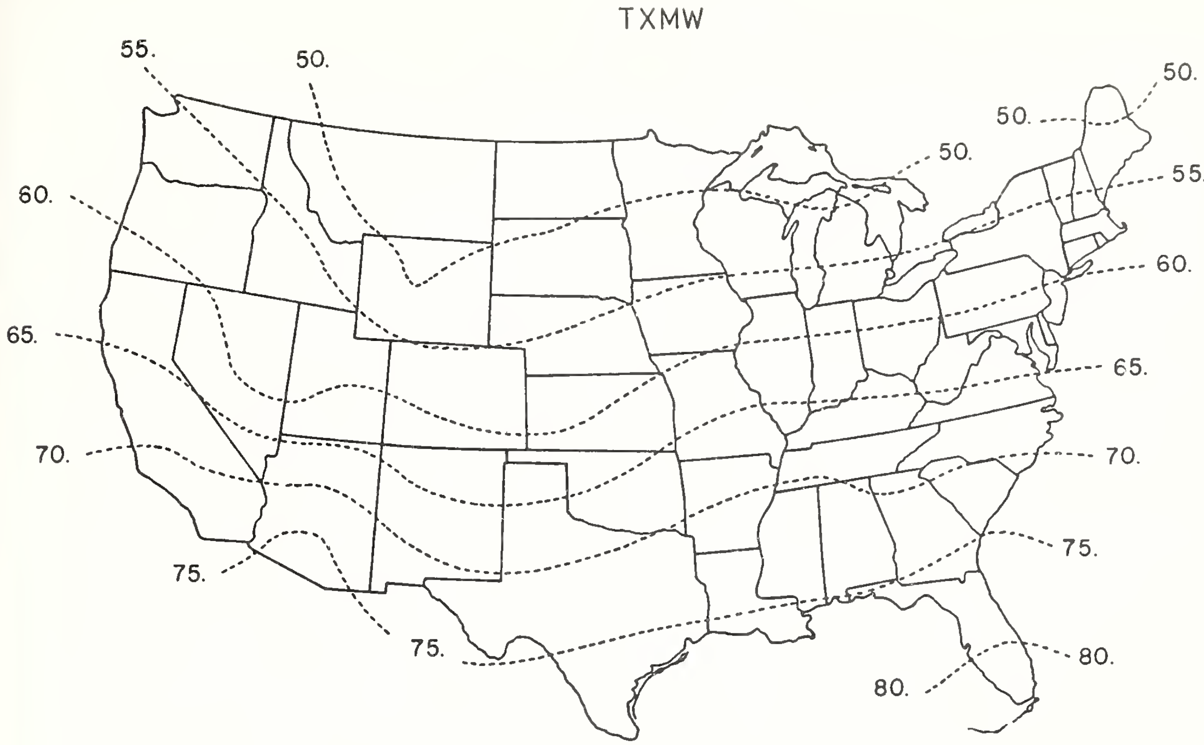

Figure 10.5
Distribution of TXMW within the contiguous United States.

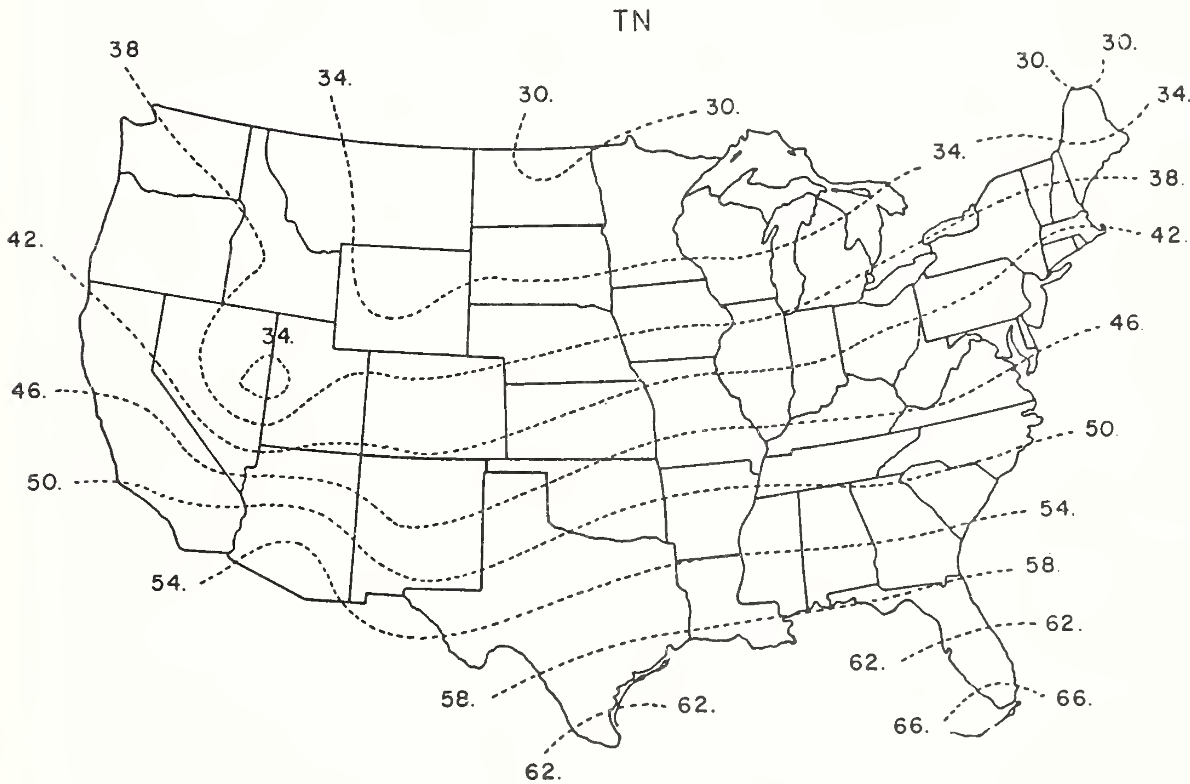

Figure 10.6
Distribution of TN within the contiguous United States.

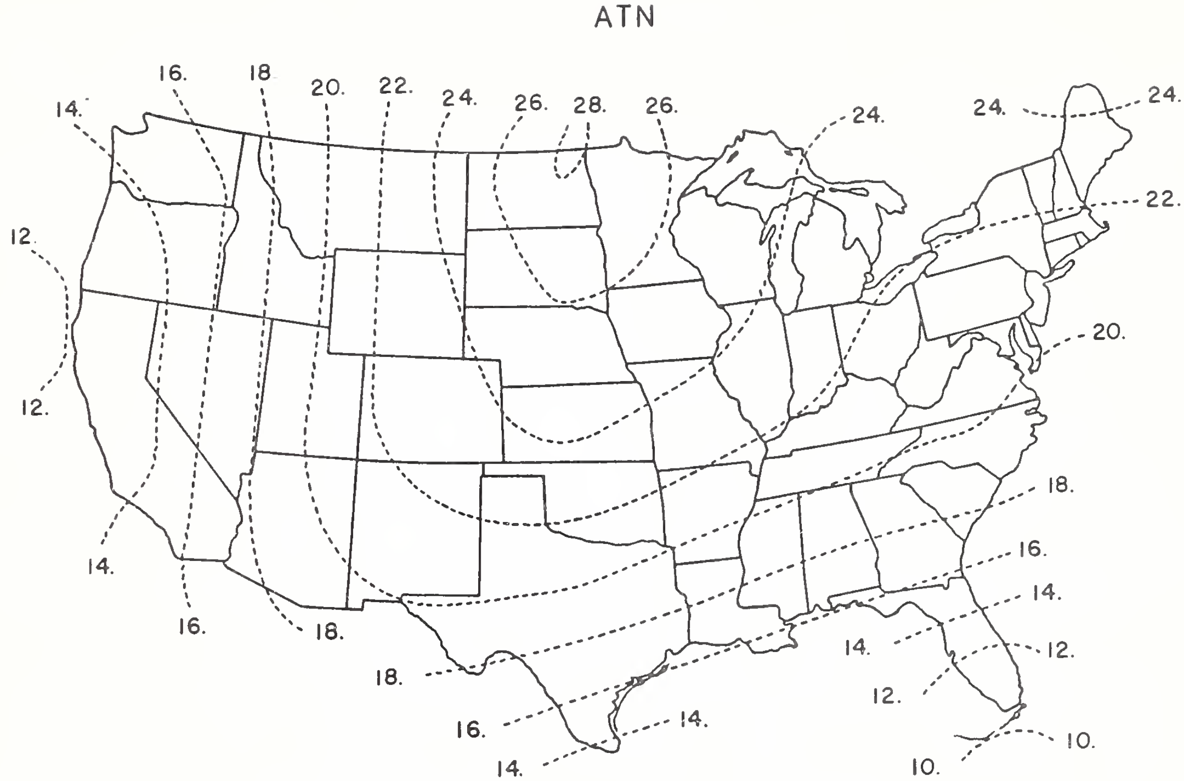

Figure 10.7
Distribution of ATN within the contiguous United States.

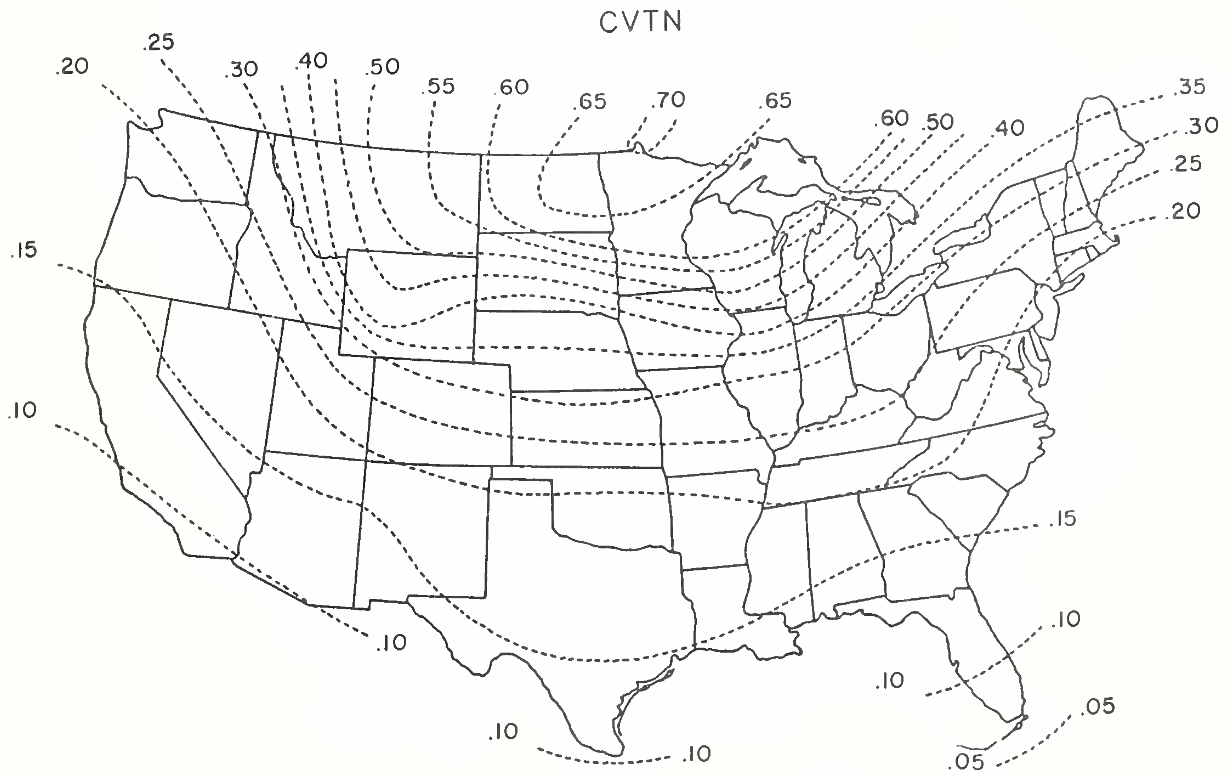

Figure 10.8
Distribution of CVTN within the contiguous United States.

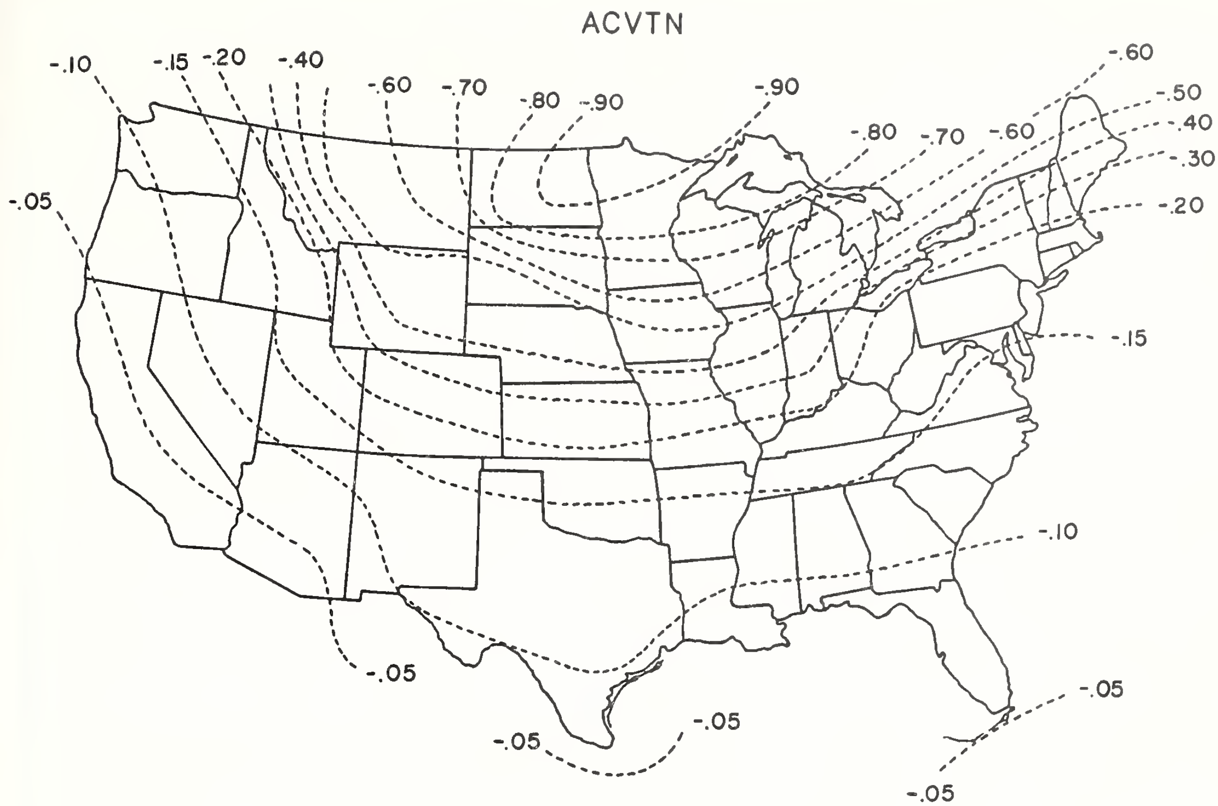

Figure 10.9
Distribution of ACVTN within the contiguous United States.

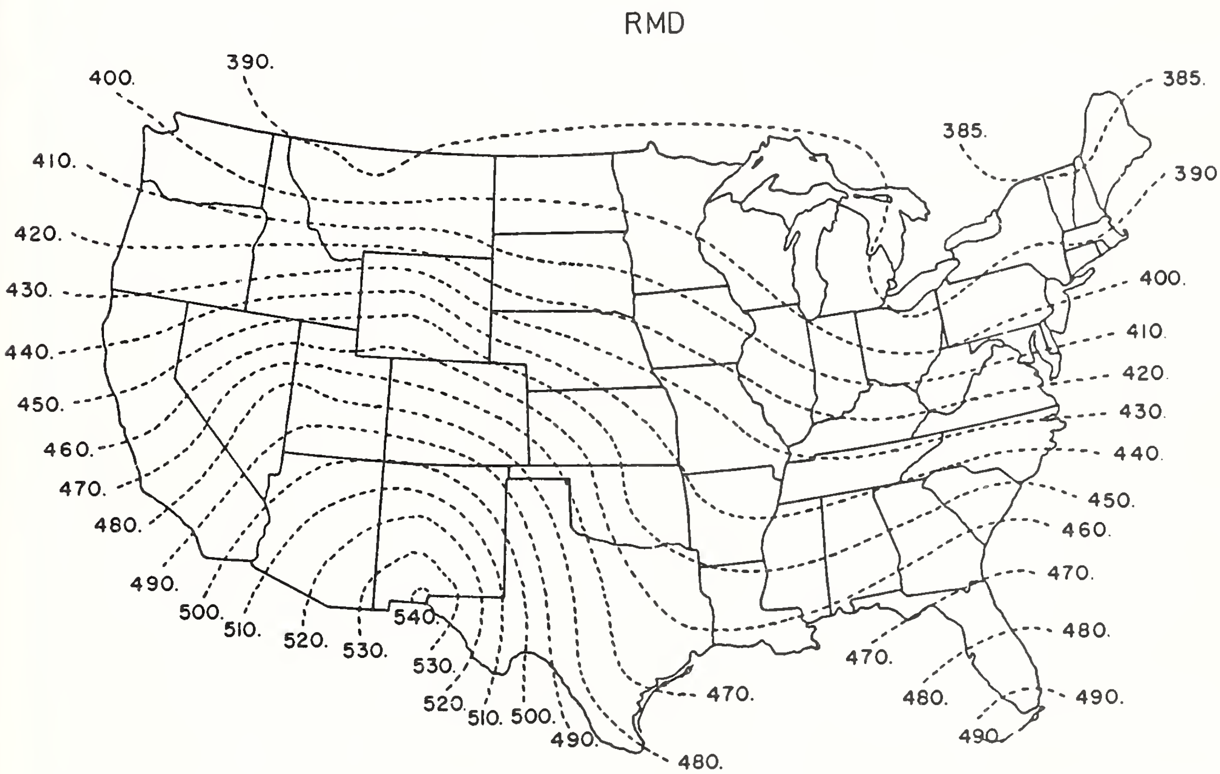

Figure 10.10
Distribution of RMD within the contiguous United States.

AR

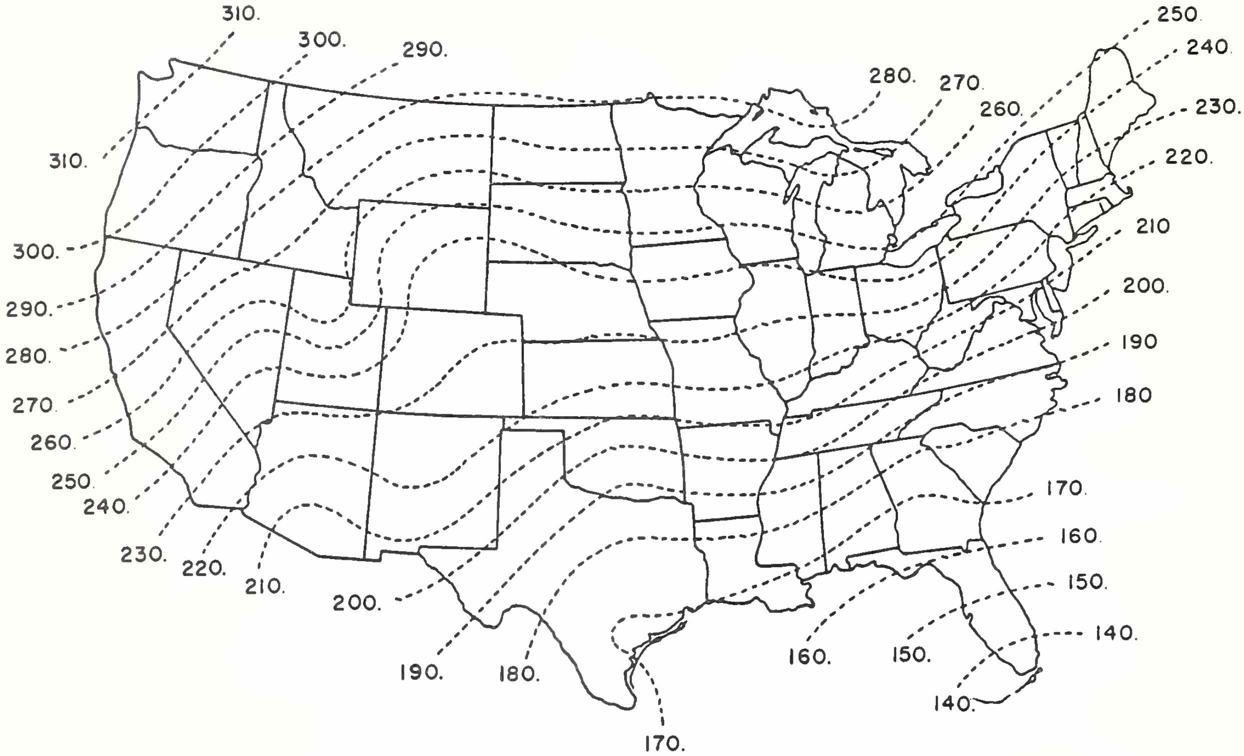

Figure 10.11
Distribution of AR within the contiguous United States.

RMW

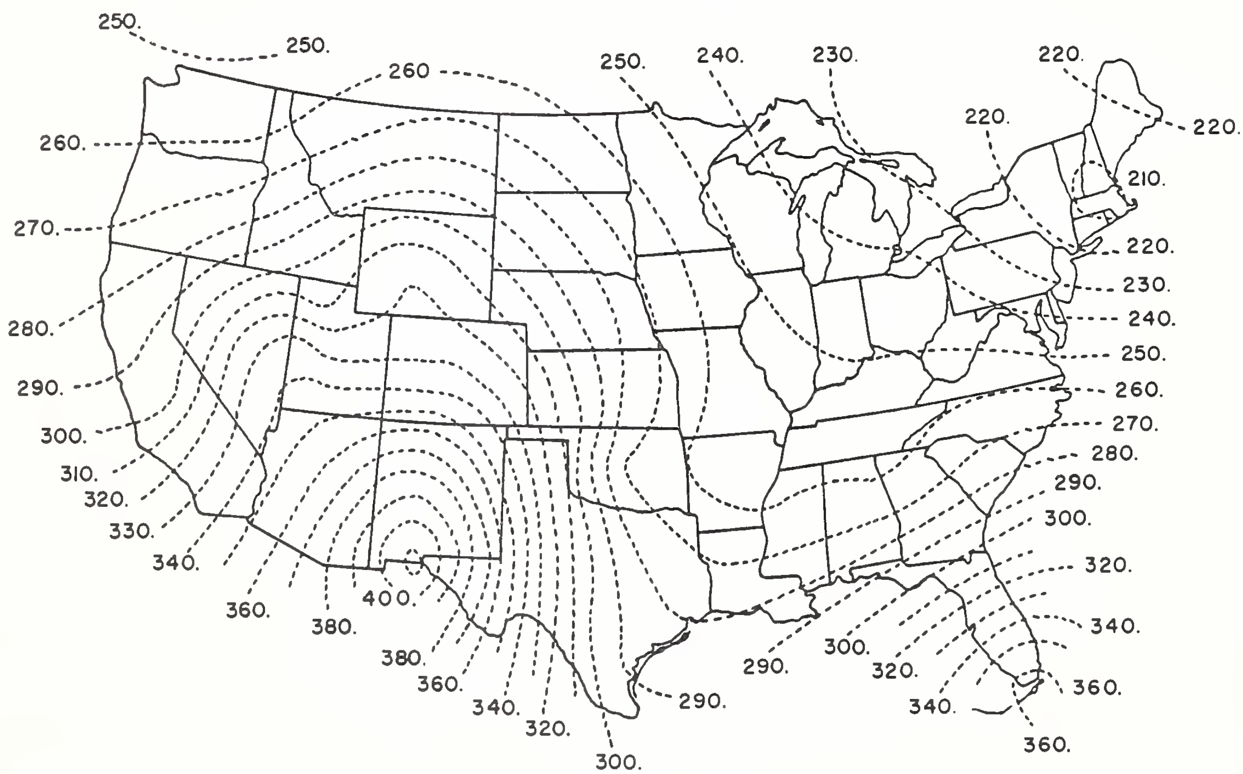

Figure 10.12
Distribution of RMW within the contiguous United States.

11. SAMPLE DATA SETS FOR THE FIELD-SCALE VERSION

J.W. Skiles

INTRODUCTION

Information in this chapter is provided so that two example simulation experiment data files and results may be compared with the data files and simulation results the user obtains when using data files he or she constructs. Within the bounds of word representation and word size, the user should produce a SUMARY file for each of the two examples that matches the SUMARY files presented in this chapter.

To construct his or her data files and to accomplish this comparison, the user should be thoroughly familiar with tables 2.3, 2.4, and 2.5 in chapter 2. The user should pay particular attention to the units and the ranges given for the variables listed in those tables as these will not be repeated here. Should the user wish to generate the weather record, he or she must also be familiar with the information in the tables and figures in chapters 4 and 10.

EXAMPLE NO. 1 - ONE SITE, FIVE PLANT SPECIES, STEER GRAZING

The Climate File

Suppose for the first example, that the locale to be simulated has a weather station at which all five weather variables have been collected for a sufficiently long time and therefore generating the climate file using the climate generator is not needed. It is assumed that the weather records are in a proper format for use by the SPUR code. A segment of a weather file that might be used for this experiment is shown in figure 11.1. See table 2.3 for the format used by SPUR to read this information. In figure 11.1 the precipitation, maximum temperature, and minimum temperature variables are in centimeters and Celsius, respectively. The appropriate switch (KONVRT) in the SPUR simulation control, hydrology, and soils file must be set to read variables with these units.

(A weather generator data file for this locale is shown in figure 11.2 and may be used if the actual weather record is not long enough for the desired SPUR simulations. The first 15 lines of weather data generated by the weather generator using the data file shown in figure 11.2 are shown in figure 11.3. Note that the precipitation is reported in centimeters and that the temperatures are in degrees Celsius.)

The Simulation Control, Soils, and Hydrology File

For the first example, assume a starting year of 1971, a simulation to be done lasting one year starting on day one of month one. The weather data are to be read with precipitation and temperatures in metric units. The field will be 100.0 acres in size with one site. The site is located at 41.0 degrees latitude at an elevation of 6,500.0 ft. The weather station from which the weather data came is also at 6,500.0 ft. The site has a slope of 0.0 and an aspect of 180.0 degrees. The site will have four soil layers of 3.0-, 3.0-, 12.0-, and 6.0-inch depth, respectively. Each soil layer will have a porosity of 0.4642. The first two soil layers have a 1/3-bar water content of 0.2000 while the third and fourth soil layers have a 1/3-bar water content of 0.2408. Layers one and two have 15-bar water contents of 0.0700 and the last two soil layers have 0.1390 for the 15-bar water content. The saturated-soil hydrologic conductivity for each layer is 0.5000, 0.5000, 0.0250, and 0.0100, respectively. The curve number to be used is 60.0, the evaporation parameter is 0.13, the rooting depth is 18 inches and the initial soil moisture is 0.50 (a fraction of field capacity). The crack factor is also 0.50.

The snow gage-catch correction factor is 1.0, while the maximum-melt factor for rain and the minimum-melt factor for rain are 5.0 and 3.0, respectively. The wind-adjustment factor is 0.2 and the maximum-accumulated-snow-water equivalent is 800.0. The areal depletion curve type is 5.0, the maximum negative melt factor is 0.6 and the weight for current snowpack temperature is 0.9. The temperature for nonrain melt of the snowpack is 0.0, the temperature to separate rain from snow is 0.0, the liquid-water holding capacity of the snowpack is 0.02, and the constant daily melt at the snowpack interface is 0.3. The snow water equivalent at the beginning of the simulation is 0.0.

Figure 11.4 is the data file constructed from the information presented in the preceding paragraphs.

The Plant-Component File

For this same example, assume that five plant species (functional groups) are to be simulated for this field. The number of parameters and critical values are 29 and 8, respectively. To distinguish the various plant species from one another, the user must provide the SPUR code with distinctive parameter and critical value information for each plant species. The user is directed to the temperature-response curve information and the critical value information shown in figure 11.5. Note that the simulated species are separated with these variables in particular. Differences in the other plant parameters also distinguish the plant species.

The site initial conditions are shown in figure 11.5. The soil inorganic-nitrogen concentration is 0.01, the dead root biomass is 610.0, the litter biomass is 147.0 and the soil organic matter is 1800.0. The phytomass compartment levels for green biomass (PHYTM 1) for all five plant species are all 0.0 since the simulation starts on the first day in January, the middle of winter. The root biomass levels (PHYTM 2) reflect the dominant plant species on the field to be simulated (warm-season grasses are dominant).

Year	Day	Precip. (cm)	Max. temp. (°C)	Min. temp. (°C)	Solar rad. (langleys)	Wind run (km)

```
....:....1....:....2....:....3....:....4....:....5....:....6....:....7....:....8
   71    1      0.250      4.000     -6.000    185.000    160.189
   71    2      0.890     -4.000    -11.000    195.000    160.189
   71    3      0.000    -12.000    -15.000    187.000    246.618
   71    4      0.000    -14.000    -22.000    210.000    142.903
   71    5      0.000    -16.000    -24.000    285.000    160.189
   71    6      0.000    -10.000    -26.000    299.000    142.903
   71    7      0.000     -7.000    -28.000    242.000    246.618
   71    8      0.000      3.000    -19.000    209.000    315.761
   71    9      0.000      6.000     -7.000    209.000    229.332
   71   10      0.000     11.000     -6.000    209.000    315.761
   71   11      0.000      4.000    -12.000    246.000     91.045
   71   12      0.000     -7.000    -12.000     88.000     73.760
   71   13      0.000      1.000    -15.000    249.000    194.760
   71   14      0.000     -1.000    -12.000    182.000    142.903
   71   15      0.000      5.000    -12.000    191.000    177.474
....:....1....:....2....:....3....:....4....:....5....:....6....:....7....:....8
```

Figure 11.1
The first 15 records of a representative climate file showing the five abiotic variables required on a daily basis for the SPUR operation. (The first and last lines are rulers to aid in locating data by column and not part of the output file.)

```
....:....1....:....2....:....3....:....4....:....5....:....6....:....7....:....8
  WEATHER GENERATION PARAMETERS - EXAMPLE NO. 1
    1    0    0    1    1 1971    1    1       41.0
       233        167        545       6985
 .360 .414  .489  .527  .597  .488  .425  .373  .444  .386  .398  .343
 .125 .176  .225  .206  .251  .282  .293  .255  .159  .123  .133  .131
 .998 .924  .833  .864  .749  .689  .742  .737  .735  .794  .942  .967
 .064 .071  .117  .159  .283  .302  .219  .222  .214  .191  .091  .065
 64.0    27.0    0.205    -.13
 54.5
 36.0    23.6    0.35     -.38
 450.0   235.
 315.0
  13.30     7.64
  14.0  15.0  15.0  14.0  12.0  11.0  10.0  10.0  11.0  11.0  14.0  15.0
....:....1....:....2....:....3....:....4....:....5....:....6....:....7....:....8
```

Figure 11.2
A representative parameter file for the generation of weather data. The information shown is derived from data in chapter 10. (The first and last lines are rulers to aid in locating data by column and are not part of the output file.)

As this is a perennial-plant rangeland system being simulated, the propagule compartment (PHYTM 3) for each plant species is set to 0.0. The standing-dead compartment (PHYTM 4) reflects the woody portion of the shrub plant species as well as the dominance of the warm-season grasses. The location parameters establish the decomposition rates for the field to be simulated.

The Animal-Component File

For this example, assume further that there are no wildlife species to harvest the forage but that six steers are to be grazed. The animals are 400.0 days old and weigh 316.0 kg when they are turned out on the field on Julian day 152.0. The animals are to be taken off the field on Julian day 274.0. The steer diet is not to be supplemented.

Since 5 plant species are to be simulated, there are 10 steer diet preferences which must be supplied, 2 (live and dead) for each forage species. This preference vector must sum to 1.0.

```
                       Max.      Min.      Solar       Wind
 Day        Precip.    temp.     temp.     rad.        run
            (cm)       (°C)      (°C)    (langleys)   (km)

....:....1....:....2....:....3....:....4....:....5....:....6....:....7....:....8
    1       0.00000   -0.13240  -6.74291 226.07524 593.10400
    2       0.00000   12.20017 -10.91624 251.04068 995.16357
    3       0.00000   16.79919  -7.44780 175.81389 498.92038
    4       0.09508    0.65269 -14.18047 111.33048 476.34634
    5       0.00000    0.33927 -17.70908 233.34613 730.57367
    6       0.00000   -0.80377 -12.33722 246.35468 642.79108
    7       0.00000   -5.49039 -20.73252 206.40863 713.47314
    8       0.00000    3.74008  -9.30746 195.53789 568.25732
    9       0.00000   -0.34773  -9.88732 261.18649 563.53943
   10       0.00000    0.07611 -10.43368 262.97061 425.39032
   11       0.00000    4.67872  -7.11598 199.76561 457.60953
   12       0.00000    7.02109  -6.11167 260.92810 455.32294
   13       0.00000    4.61610  -6.36682 268.817691190.39697
   14       0.00000    8.62204  -4.69670 164.22290 257.01022
   15       0.00000    5.50195 -13.59286 273.12357 480.76746
....:....1....:....2....:....3....:....4....:....5....:....6....:....7....:....8
```

Figure 11.3
The first 15 records of a weather file produced using the weather generator file from figure 11.2. (The first and last lines are rulers to aid in locating data by column and are not part of the output file.)

```
....:....1....:....2....:....3....:....4....:....5....:....6....:....7....:....8
SPUR FIELD-SCALE TEST - EXAMPLE NO. 1
 1971   01    1    1    1      100.0     1 0 1 0 0 0 0 0
 (11X,5F10.5)
    1    4
     100.0      60.0      18.0      0.13     180.0       0.0       0.5       0.0
       0.5
    0.4642    0.4642    0.4642    0.4642
    0.2000    0.2000    0.2408    0.2408    0.0700    0.0700    0.1390    0.1390
    0.5000    0.5000    0.0250    0.0100
    3.0000    3.0000    12.000    6.0000
      41.0    6500.0    6500.0
       1.0       5.0       3.0       0.2      800.       5.0       0.6       0.9
       0.0       0.0      0.02       0.3
       0.0
....:....1....:....2....:....3....:....4....:....5....:....6....:....7....:....8
```

Figure 11.4
A representative simulation control, hydrology, and soils file for one site with four soil layers. (The first and last lines are rulers to aid in locating data by column are and not part of the output file.)

There are no physical limitations to any of these forage classes, hence this vector will have 1.0 for all 10 entries. Since only one site is to be simulated, the preference for that site by the steers is 1.0 and the physical limitation to that site is 1.0 (no limitation.)

The economics report flag is to be set to one so that a report is printed. Prices per weight class of the finished steers are 70.0, 67.0, 64.0, 63.0, and 65.0 cents per pound. The discount rate is 12.0 and the costs per head per month sum to 6.00.

An animal-component data file, constructed using the information discussed in the preceding paragraphs, is shown in figure 11.6.

<u>Results for Example No. 1</u>

The field-scale version of SPUR has been programed to write many different files to disk storage devices, depending on the values of the print switches. These print switches provide the user with powerful tools for use in ascertaining how the SPUR model operates. The user should review

```
....:....1....:....2....:....3....:....4....:....5....:....6....:....7....:....8
    5   29    8
   WARM-SEASON GRASSES
   COOL-SEASON GRASSES
   WARM-SEASON FORBS
   COOL-SEASON FORBS
   SHRUBS
  75.00000  25.00000  20.00000  12.00000  15.00000
   0.40000   2.00000   0.15000   1.30000   1.30000
  45.00000  37.00000  45.00000  35.00000  40.00000
  27.00000  20.00000  27.00000  20.00000  21.00000
   5.00000   3.00000   5.00000   3.00000   3.00000
  25.00000  10.00000  15.00000   7.00000   8.50000
   9.96000   6.29000   7.04000   4.75000   6.40000
   0.70000   0.70000   0.70000   0.70000   0.70000
  10.00000  10.00000   4.00000   4.00000   5.00000
  -0.00010  -0.00020  -0.00040  -0.00050  -0.00002
  -0.25000  -0.40000  -0.60000  -0.65000  -0.00025
   0.05000   0.05000   0.06000   0.06000   0.00070
  -0.00900  -0.01000  -0.01000  -0.01000  -0.00090
  -0.00500  -0.00600  -0.00600  -0.00600   0.00000
   0.00400   0.00400   0.00400   0.00500   0.00050
   0.01500   0.02000   0.03000   0.03000   0.03000
   0.01000   0.02000   0.05000   0.05000   0.04000
   0.00500   0.00500   0.00500   0.00500   0.00500
   0.00500   0.01000   0.00500   0.00500   0.01000
  22.00000  72.00000  30.00000  15.00000  19.00000
   0.06000   0.06000   0.05000   0.05000   0.05000
   0.00000   0.00000   0.00000   0.00000   0.00000
   0.01000   0.01000   0.01000   0.01000   0.01000
   0.00250   0.00250   0.00100   0.00050   0.00150
   0.00500   0.00400   0.00200   0.00100   0.00050
   0.00800   0.00900   0.01000   0.01100   0.01000
-130.00000-115.00000-120.00000-110.00000-130.00000
   0.00300   0.00300   0.00200   0.00200   0.00100
   0.42000   0.42000   0.21000   0.21000   0.30000
   3.00000   3.00000   3.00000   3.00000   3.00000
  -2.00000  -6.00000  -1.00000  -3.00000  -4.00000
  12.50000   8.50000  13.00000   9.00000   8.50000
 -12.00000 -10.00000 -12.00000  -8.00000  -8.00000
  -5.00000  -3.00000  -5.00000  -3.00000  -1.00000
 212.00000 196.00000 205.00000 190.00000 190.00000
 227.00000 213.00000 220.00000 200.00000 230.00000
 274.00000 259.00000 263.00000 244.00000 270.00000
   0.01000 610.00000 147.000001800.00000 - Site Initial Conditions
   0.00000   0.00000   0.00000   0.00000   0.00000 - PHYTM 1
 256.39999  62.70000  35.00000  32.40000  45.00000 - PHYTM 2
   0.00000   0.00000   0.00000   0.00000   0.00000 - PHYTM 3
  54.00000  11.00000   3.00000   6.00000  30.00000 - PHYTM 4
   0.01000   0.09000   0.00250  -0.02800   4.00000   2.23000 - Location
                                                               Parameters
....:....1....:....2....:....3....:....4....:....5....:....6....:....7....:....8
```

Figure 11.5
A representative plant parameter file for the simulation of five plant species on one site. (The first and last lines are rulers to aid in locating data by column and are not part of the output file.)

```
....:....1....:....2....:....3....:....4....:....5....:....6....:....7....:....8
    0
    6
00000
     509.0       152.0       274.0       400.0       316.0
      0.13        0.08        0.16        0.09        0.12        0.07        0.14        0.09
      0.07        0.05
      1.00        1.00        1.00        1.00        1.00        1.00        1.00        1.00
      1.00        1.00
       1.0
       1.0
    1
     70.00       67.00       64.00       63.00       65.00
     12.00        6.00
....:....1....:....2....:....3....:....4....:....5....:....6....:....7....:....8
```

Figure 11.6
A representative animal parameter file for the simulation of six steers grazing on one site with no wildlife. (The first and last lines are rulers to aid in locating data by column and not part of the output file.)

the discussion on print-switch values and the examples given for each print switches shown in chapter 2.

As was mentioned in chapter 2, the SPUR code has a built-in, report-producing subprogram from which some output is generated no matter what the values are of any of the print switches. This output in report form, called the SUMARY report, is shown in figure 11.7.

EXAMPLE NO. 2. TWO SITES, SEVEN PLANT SPECIES, STEER AND WILDLIFE GRAZING

The Climate File

The field to be simulated in this example is at a different latitude from the previous example and has no long-term weather record. The simulation experiment is to last for 20 years, so weather generation is necessary. A weather generator data file for this field is shown in figure 11.8. The first 15 lines of the weather file produced by the data file in figure 11.8 are shown in figure 11.9.

The Simulation Control, Soils, and Hydrology File

Figure 11.10 is the control, soils, and hydrology file for this example. The field to be simulated is 3,000.0 acres in size and with two sites. The simulation is for 20.0 years, to begin on day 1.0 of month 1.0 in the year 1980.

The first site has five soil layers, is 2,400.0 acres, has an aspect of 180.0 degrees and a slope of 0.0. The hydrology and runoff information is as shown. The second site has six soil layers, is 600.0 acres, has an aspect of 0.0 and a slope of 0.0. The hydrology and runoff information is as shown.

The field is at 43.6 degrees latitude with an elevation of 5,500.0 ft. Since the weather record is generated specifically for this field, the elevation of the temperature measurement location is set to 5,500.0 as well, since no elevation adjustment is needed. The snow accumulation and melt information is as shown.

The Plant-Component File

When simulating more than one site, the user must supply initial conditions and beginning phytomass levels for each site. This is shown in figure 11.11. Note that the initial conditions for the sites are different from each other.

Also note that the proposed simulation uses the maximum of seven plant species. However, not all species are present on both sites. This distinguishes the plant communities for the two sites. Species 5 and 6 are not present on site 1, while species 1 and 4 are not present on site 2. This difference is accomplished by setting the initial root biomass (PHYTM 2) for those species to 0.0.

The Animal-Component File

In this simulation experiment, three wildlife species are to graze the field. In this instance, a resident deer herd is on the field all year. The density of the herd varies, however, from 250.0 animals in the first 3 months of the year, to 100.0 animals in the middle of the year, to 250.0 at the last of the year.

From day 1.0 to day 90.0, the animals prefer to graze site one 10 percent and site two 90 percent of the time on any given day. Since seven plant species are being simulated, there are 14 forage classes for which wildlife preferences must be assigned. The second wildlife herd grazes on the field from day 91.0 to day 335.0 and prefers site one 40 percent and site two 60 percent of the time on any given day. Again, 14 wildlife preferences for forage must be assigned. From day 336.0 to the end of the year, the wildlife site preferences

*** SIMULATION DEFINITION ***

FIRST YEAR: 1971 NUMBER OF YEARS: 1 FIRST MONTH: 1 FIRST OAY: 1 NUMBER OF SITES: 1
TOTAL FIELO AREA (AC): 100.00 FIELD LATITUOE (OEGREES): 41.00
FIELO ELEVATION: 6500.00 TEMPERATURE ELEVATION: 6500.00

ENGLISH/METRIC CONVERSION SWITCH = 1, PRINT-SWITCH VALUES: IP1 = 0 IP2 = 1 IP3 = 0 IP4 = 0 IP5 = 0 IP6 = 0 IP7 = 0

++ SOILS INFORMATION ++

REPORT FOR SITE NO.	NO. SOIL LAYERS	AREA	CONO.-I CURVE NO.	CROP FACTOR	ROOTING OEPTH	CRACK FACTOR
1	4	100.0	60.00	0.500	18.000	0.000

SOIL-LAYER PARAMETERS

LAYER		1	2	3	4
SOIL POROSITY	(IN/IN):	0.464	0.464	0.464	0.464
SOIL WATER AT 0.3 BAR	(IN/IN):	0.200	0.200	0.241	0.241
SOIL WATER AT 15 BARS	(IN/IN):	0.070	0.070	0.139	0.139
SOIL WATER AT 50 BARS	(IN/IN):	0.050	0.050	0.117	0.117
SAT.-SOIL CONDUCTIVITY	(IN/HR):	0.500	0.500	0.025	0.010
ACCUMULATED SOIL OEPTH	(IN) :	3.000	6.000	18.000	24.000
MAXIMUM STORAGE	(IN) :	1.242	1.242	4.168	2.084
FIELD CAPACITY	(IN) :	0.449	0.449	1.488	0.744

++ SNOW ACCUMULATION ANO MELT PARAMETERS ++

GAUGE-CATCH CORRECTION FACTOR 1.000
MAXIMUM-MELT FACTOR (MM/C*DAY) 5.00000
MINIMUM-MELT FACTOR (MM/C*DAY) 3.00000
WIND FUNCTION FOR RAIN-ON-SNOW PERIODS (MM/MB*DAY) 0.20000
WATER EQUIVALENT ABOVE WHICH THERE IS 100% SNOW COVER 800.00000
AREAL DEPLETION CURVE TYPE NUMBER 5.00
NEGATIVE MELT FACTOR (MM/C) 0.60000
ANTECEOENT-TEMPERATURE WEIGHT 0.90
TEMPERATURE FOR MELT OURING NONRAIN PERIOOS (C) 0.00000
TEMPERATURE TO DIFFERENTIATE RAIN FROM SNOW (C) 0.00000
PERCENT LIQUID WATER IN SNOWPACK (OECIMAL)0.02
DAILY GROUNDMELT (MM/OAY) 0.30000

++ PLANT-COMPONENT INPUTS ++

NUMBER OF PLANT SPECIES = 5
NUMBER OF PARAMETERS PER PLANT SPECIES = 29
NUMBER OF CRITICAL VALUES PER PLANT SPECIES = 8

SPECIES 1 IS WARM SEASON GRASSES
SPECIES 2 IS COOL SEASON GRASSES
SPECIES 3 IS WARM SEASON FORBS
SPECIES 4 IS COOL SEASON FORBS
SPECIES 5 IS SHRUBS

SPECIES	1	2	3	4	5
PARAMETER 1	75.00000	25.00000	20.00000	12.00000	15.00000
PARAMETER 2	0.40000	2.00000	0.15000	1.30000	1.30000
PARAMETER 3	45.00000	37.00000	45.00000	35.00000	40.00000
PARAMETER 4	27.00000	20.00000	27.00000	20.00000	21.00000
PARAMETER 5	5.00000	3.00000	5.00000	3.00000	3.00000
PARAMETER 6	25.00000	10.00000	15.00000	7.00000	8.50000
PARAMETER 7	9.96000	6.29000	7.04000	4.75000	6.40000
PARAMETER 8	0.70000	0.70000	0.70000	0.70000	0.70000
PARAMETER 9	10.00000	10.00000	4.00000	4.00000	5.00000
PARAMETER 10	-0.00010	-0.00020	-0.00040	-0.00050	-0.00002

PARAMETER 11	-0.25000	-0.40000	-0.60000	-0.65000	-0.00025
PARAMETER 12	0.05000	0.05000	0.06000	0.06000	0.00070
PARAMETER 13	-0.00900	-0.01000	-0.01000	-0.01000	-0.00090
PARAMETER 14	-0.00500	-0.00600	-0.00600	-0.00600	0.00000
PARAMETER 15	0.00400	0.00400	0.00400	0.00500	0.00050
PARAMETER 16	0.01500	0.02000	0.03000	0.03000	0.03000
PARAMETER 17	0.01000	0.02000	0.05000	0.05000	0.04000
PARAMETER 18	0.00500	0.00500	0.00500	0.00500	0.00500
PARAMETER 19	0.00500	0.01000	0.00500	0.00500	0.01000
PARAMETER 20	22.00000	72.00000	30.00000	15.00000	19.00000
PARAMETER 21	0.06000	0.06000	0.05000	0.05000	0.05000
PARAMETER 22	0.00000	0.00000	0.00000	0.00000	0.00000
PARAMETER 23	0.01000	0.01000	0.01000	0.01000	0.01000
PARAMETER 24	0.00250	0.00250	0.00100	0.00050	0.00150
PARAMETER 25	0.00500	0.00400	0.00200	0.00100	0.00050
PARAMETER 26	0.00800	0.00900	0.01000	0.01100	0.01000
PARAMETER 27	-130.00000	-115.00000	-120.00000	-110.00000	-130.00000
PARAMETER 28	0.00300	0.00300	0.00200	0.00200	0.00100
PARAMETER 29	0.42000	0.42000	0.21000	0.21000	0.30000
CRITICAL VALUE 1	3.00000	3.00000	3.00000	3.00000	3.00000
CRITICAL VALUE 2	-2.00000	-6.00000	-1.00000	-3.00000	-4.00000
CRITICAL VALUE 3	12.50000	8.50000	13.00000	9.00000	8.50000
CRITICAL VALUE 4	-12.00000	-10.00000	-12.00000	-8.00000	-8.00000
CRITICAL VALUE 5	-5.00000	-3.00000	-5.00000	-3.00000	-1.00000
CRITICAL VALUE 6	212.00000	196.00000	205.00000	190.00000	190.00000
CRITICAL VALUE 7	227.00000	213.00000	220.00000	200.00000	230.00000
CRITICAL VALUE 8	274.00000	259.00000	263.00000	244.00000	270.00000

SITE-NUMBER- 1 INITIAL CONDITIONS:

PLANT SPECIES	STANDING GREEN (C)	STANDING GREEN (N)	LIVE ROOTS (C)	LIVE ROOTS (N)	PROPAGULES (C)	PROPAGULES (N)	STANOING DEAD (C)	STANDING DEAD (N)
1	0.000	0.000	256.400	2.564	0.000	0.000	54.000	0.270
2	0.000	0.000	62.700	0.627	0.000	0.000	11.000	0.055
3	0.000	0.000	35.000	0.350	0.000	0.000	3.000	0.015
4	0.000	0.000	32.400	0.324	0.000	0.000	6.000	0.030
5	0.000	0.000	45.000	0.450	0.000	0.000	30.000	0.150

NON-SPECIES-SPECIFIC INITIAL VALUES:

OEAD ROOTS (C)	OEAD ROOTS (N)	LITTER (C)	LITTER (N)	ORGANIC MATTER (C)	ORGANIC MATTER (N)	SOIL INORGANIC NITROGEN
610.000	3.660	147.000	1.470	1800.000	72.000	0.010

NON-SITE-, NON-SPECIES-SPECIFIC PARAMETERS:

0.010 0.090 0.002 -0.028 4.000 2.230

++ STEER-GROWTH-COMPONENT INPUTS ++

STEER HERO SIZE 6

AVERAGE STEER PARAMETERS

MEAN ASYMPTOTIC WEIGHT FOR MATURE STEER (KG) 509.00000

DAY STEER STARTS GRAZING 152.

OAY STEER STOPS GRAZING 274.

AGE OF STEER AT TIME GRAZING STARTS (DAYS) 400.00000

WEIGHT OF STEER AT TIME GRAZING STARTS (KG) 316.00000

SPECIES PREFERENCE

SPECIES	GREEN	DEAD
1	0.130	0.080
2	0.160	0.090
3	0.120	0.070
4	0.140	0.090
5	0.070	0.050

PHYSICAL LIMITATION

SPECIES	GREEN	OEAD
1	1.000	1.000
2	1.000	1.000

3	1.000	1.000
4	1.000	1.000
5	1.000	1.000

LOCATION PREFERENCE AND LIMITATIONS

SITE	LOCATION	LIMITATION
1	1.000	1.000

++ ECONOMICS COMPONENT INPUTS ++

400-500 POUND STEERS 0.7000 DOLLARS/POUND
500-600 POUND STEERS 0.6700 DOLLARS/POUND
600-700 POUND STEERS 0.6400 DOLLARS/POUND
700-800 POUND STEERS 0.6300 DOLLARS/POUND
800-1100 POUND STEERS 0.6500 DOLLARS/POUND

DISCOUNT RATE = $12.0000 ANNUAL RATE

LIVESTOCK EXPENSES = $ 6.0000 /HEAD/MONTH

1 SPUR FIELD SCALE TEST - EXAMPLE NO. 1 YEAR 1971 PAGE 3

FIELD REPORT FOR YEAR 1971

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
PRECIPITATION (IN)	0.45	0.35	0.86	2.79	3.59	0.38	0.45	0.50	2.32	0.43	0.11	0.03	12.26
INFILTRATION (IN)	0.45	0.20	1.01	2.79	3.59	0.38	0.45	0.50	2.32	0.37	0.16	0.04	12.25
POTENTIAL ET (IN)	1.36	1.27	2.16	4.95	6.10	8.08	7.97	7.98	5.37	3.93	1.70	1.50	52.36
SOIL EVAPORATION (IN)	0.61	0.21	0.76	1.07	1.50	0.31	0.35	0.45	1.07	0.35	0.17	0.04	6.88
PLANT TRANSPIRATION (IN)	0.00	0.00	0.00	0.07	1.42	2.22	0.10	0.05	0.63	0.26	0.00	0.00	4.75
DEEP PERCOLATION (IN)	0.00	0.00	0.00	0.00	0.55	0.28	0.07	0.05	0.03	0.03	0.02	0.02	1.06
PLANT-AVAILABLE WATER (IN)	1.03	1.02	1.28	2.74	2.18	0.00	0.00	0.00	0.62	0.38	0.37	0.37	9.98
MONTHEND PLANT BIOMASS (KG/HA)	0.0	0.0	0.0	96.7	360.8	765.2	647.8	458.1	233.2	17.6	0.2	0.0	
LIVESTOCK WT (KG)	0.0	0.0	0.0	0.0	0.0	334.7	354.7	373.2	376.0	376.1	0.0	0.0	60.1

*********** ECONOMICS REPORT FOR 1971***

STEER PURCHASE COST	ANNUAL VARIABLE COST	TOTAL ANNUAL COSTS	POUNDS OF BEEF SOLD	GROSS REVENUE	NET REVENUE	NET PRESENT VALUE
2675.15	24.40	2699.55	4975.02	3233.76	534.21	513.21

******* NET PRESENT VALUE 513.21

SITE REPORT FOR SITE NUMBER 1 FOR YEAR 1971

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
PRECIPITATION (IN)	0.45	0.35	0.86	2.79	3.59	0.38	0.45	0.50	2.32	0.43	0.11	0.03	12.26
INFILTRATION (IN)	0.45	0.20	1.01	2.79	3.59	0.38	0.45	0.50	2.32	0.37	0.16	0.04	12.25
POTENTIAL ET (IN)	1.36	1.27	2.16	4.95	6.10	8.08	7.97	7.98	5.37	3.93	1.70	1.50	52.36
SOIL EVAPORATION (IN)	0.61	0.21	0.76	1.07	1.50	0.31	0.35	0.45	1.07	0.35	0.17	0.04	6.88
PLANT TRANSPIRATION (IN)	0.00	0.00	0.00	0.07	1.42	2.22	0.10	0.05	0.63	0.26	0.00	0.00	4.75
DEEP PERCOLATION (IN)	0.00	0.00	0.00	0.00	0.55	0.28	0.07	0.05	0.03	0.03	0.02	0.02	1.06
PLANT-AVAILABLE WATER (IN)	1.03	1.02	1.28	2.74	2.18	0.00	0.00	0.00	0.62	0.38	0.37	0.37	
MONTHEND PLANT BIOMASS (KG/HA)	0.0	0.0	0.0	96.7	360.8	765.2	647.8	458.1	233.2	17.6	0.2	0.0	

Figure 11.7
Simulation report generated by the field-scale version of SPUR for one site with four soil layers, five plant species, and six grazing steers.

are 0.1 and 0.9 for site one and site two, respectively. Forage preferences must again be assigned.

In the case of wildlife species 2, the user has made an error in entering the forage pereferences. That vector, which should sum to 1.0, actually totals 1.0032. The SPUR code will therefore change the preference vector so that it will be (slightly) less than or equal to 1.0. The program does this by normalizing each element in the vector to the sum of all the preferences. The preferences for this wildlife species shown in the SUMARY file reflect this operation.

Each wildlife herd is composed of a specified number of average animals. The user must supply the dry-matter intake per day of such an average animal for each herd. For this example, that is 1.0 kg for all three herds.

A total of 430 steers are to be grazed for this example. They are to be turned out on day 115.0, weigh 250.0 kg, and be one year old on that day. The steers are to be removed from the field on day 161.0. The breed of animal to be used has an asymptotic growth weight of 450.0 kg. The steer diets are to be supplemented with 1.0 kg of 80 percent digestible supplement starting on day 145.0 and continuing until the animals are removed from the field.

Steer preference for each forage class as well as the physical limitation for each forage class must be assigned. Since 14 forage classes are being simulated, there will be 14 numbers in each of these vectors. The steers have an equal preference for each of the two sites, so the user will enter 0.5 and 0.5 in that vector. There are no physical limitations for the steers getting to either site so that vector is 1.0 and 1.0. An economics report is to be printed, so the economics flag is set to 1, and the information for the economics component must be supplied.

Figure 11.12 is the data file for the animals simulated in this example.

<u>Results for Example No. 2</u>

Figure 11.13 is the SUMARY file produced for the first year of the simulation outlined in Example No. 2. For each simulated year a field report and report for each site is written.

```
....:....1....:....2....:....3....:....4....:....5....:....6....:....7....:....8
 WEATHER GENERATION FILE - EXAMPLE NO. 2
   1    0    0    0    1 1980    1   20       43.6
      233        167         545       6985
 .584  .530  .497  .404  .496  .492  .406  .466  .443  .465  .570  .500
 .258  .234  .268  .255  .193  .185  .086  .090  .112  .162  .235  .302
 .838  .998  .998  .785  .919  .991  .998  .883  .852  .886  .938  .997
 .163  .106  .126  .200  .142  .170  .095  .158  .192  .177  .139  .131
   54.9     23.0   0.183    -.087
 49.945
   38.1     16.9   0.243    -.115
  430.0   285.0
  280.0
   9.30    5.38
   9.0  10.0  11.0  10.0  10.0   9.0   9.0   8.0   9.0   9.0   9.0   9.0
....:....1....:....2....:....3....:....4....:....5....:....6....:....7....:....8
```

Figure 11.8
A representative parameter file for the generation of weather for Example No. 2. The information shown is derived from data presented in chapter 10. (The first and last lines are rulers to aid in locating data by column and are not part of the output file.)

```
....:....1....:....2....:....3....:....4....:....5....:....6....:....7....:....8
```

Day	Precip. (cm)	Max. temp. (°C)	Min. temp. (°C)	Solar rad. (langleys)	Wind run (km)
1	0.18304	17.26266	15.99891	43.90997	383.15399
2	0.05009	29.77116	25.33521	44.13159	565.40967
3	0.04305	29.37619	16.06601	44.37027	523.61859
4	0.02370	26.82170	26.82170	44.62601	200.78935
5	0.00293	17.87631	17.87631	44.89876	475.46194
6	0.05336	25.03733	17.88636	45.18851	341.56287
7	0.12576	26.23888	25.80573	45.49520	271.97958
8	0.00000	41.55072	22.77304	217.87889	388.89941
9	0.00000	51.80864	30.83824	184.59891	323.78979
10	0.00000	48.50107	28.84143	214.36598	268.84473
11	0.00000	29.74320	20.96884	186.92941	485.36612
12	0.00000	19.24129	13.35378	151.65410	392.88422
13	0.00000	8.57640	8.57640	156.36180	198.38577
14	0.00000	18.78118	11.03252	78.26379	286.39551
15	0.00000	18.59845	6.10182	168.33891	519.02167

```
....:....1....:....2....:....3....:....4....:....5....:....6....:....7....:....8
```

Figure 11.9
The first 15 records of a weather file produced using the weather generator file shown in figure 11.8. (The first and last lines are rulers to aid in locating data by column and are not part of the output file.)

```
....:....1....:....2....:....3....:....4....:....5....:....6....:....7....:....8
  SPUR FIELD-SCALE TEST - EXAMPLE NO. 2
 1980   20    2    1    1    3000.0    0 0 1 0 0 0 0 1
 (11X,5F10.5)
    1    5
    2400.0      65.0      16.0      0.14     180.0       0.0       0.5       0.0
       0.5
    0.4000    0.4000    0.4000    0.4000    0.3000
    0.2700    0.2700    0.2700    0.3300    0.2500
    0.0950    0.0950    0.0950    0.1300    0.1500
    0.5000    0.0500    0.0500    0.0005    0.7500
    3.0000    3.0000   10.0000    16.000    12.000
    2    6
      600.      60.0      50.0      0.14       0.0       0.0       0.5       0.0
       0.5
    0.5000    0.5000    0.5000    0.5000    0.4800    0.4400
    0.3820    0.3820    0.3820    0.3820    0.3900    0.2830
    0.1340    0.1340    0.1340    0.1340    0.1496    0.0910
    0.5000    0.5000    0.5000    0.5000    0.0250    1.0000
    3.0000    3.0000    2.0000    5.0000   37.0000   13.0000
      43.6    5500.0    5500.0
   1.0     5.0      3.0      0.2        800.       5.0      0.6       0.9
  0.0     0.0      0.02     0.3
  0.0
....:....1....:....2....:....3....:....4....:....5....:....6....:....7....:....8
```

Figure 11.10
A representative simulation control, hydrology, and soils file for two sites with five soil layers on the first site and six soil layers on the second site. (The first and last lines are rulers to aid in locating data by column and are not part of the output file.)

```
....:....1....:....2....:....3....:....4....:....5....:....6....:....7....:....8
   7   29    8
   SANDBURGS BLUEGRASS (POA SANDBURGII)
   BLUEGRASS - OTHER (POA SP.)
   IDAHO FESCUE (FESTUCA IDAHOENSIS)
   LOW SAGE (ARTEMISIA ARBUSCULA)
   BIG SAGE (ATREMISIA TRIDENTATA)
   BITTERBRUSH (PURSHIA TRIDENTATA)
   COOL-SEASON FORBS
  40.00000  40.00000  30.00000  11.00000  15.00000  20.00000  20.00000
   1.90000   2.00000   2.00000   2.00000   2.00000   2.10000   1.30000
  30.00000  30.00000  30.00000  35.00000  35.00000  35.00000  30.00000
  15.00000  15.00000  15.00000  15.00000  15.00000  15.00000  15.00000
   0.00000   0.00000   0.00000   2.00000   0.00000   0.00000   3.00000
  10.00000   9.00000   9.00000  12.00000  15.00000  15.00000   8.50000
   6.30000   6.40000   6.10000   5.70000   5.70000   5.70000   4.75000
   0.70000   0.70000   0.70000   0.70000   0.70000   0.70000   0.90000
   8.00000   8.00000   8.00000  10.00000  10.00000  10.00000   4.00000
  -0.00019  -0.00014  -0.00014  -0.00002  -0.00002  -0.00002  -0.00050
  -0.40000  -0.36000  -0.50000  -0.00025  -0.00030  -0.00027  -0.65000
   0.05000   0.05000   0.05000   0.00070   0.00050   0.00060   0.06000
  -0.00950  -0.00900  -0.00900  -0.00090  -0.00100  -0.00050  -0.01000
  -0.00500  -0.00500  -0.00500   0.00000   0.00000   0.00000  -0.00600
   0.00400   0.00400   0.00400   0.00050   0.00050   0.00050   0.00500
   0.02000   0.02000   0.02000   0.03000   0.03000   0.03000   0.03000
   0.01800   0.02000   0.01800   0.04000   0.03000   0.02000   0.05000
   0.00500   0.00500   0.00500   0.00500   0.00500   0.00500   0.00500
   0.01000   0.01000   0.01000   0.01000   0.01000   0.01000   0.00500
  25.00000  23.00000  17.00000  22.00000  19.00000  21.00000   8.00000
   0.06000   0.06000   0.06000   0.05000   0.05000   0.05000   0.05000
   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000
   0.01000   0.01000   0.01000   0.01000   0.01000   0.01000   0.01000
   0.00250   0.00300   0.00270   0.00150   0.00150   0.00150   0.00150
   0.00400   0.00350   0.00250   0.00050   0.00050   0.00050   0.00100
   0.00900   0.00900   0.00900   0.01000   0.01000   0.01000   0.01100
-117.00000-120.00000-115.00000-127.00000-128.00000-130.00000-110.00000
   0.00300   0.00200   0.00300   0.00100   0.00200   0.00150   0.00200
   0.42000   0.42000   0.42000   0.35000   0.31000   0.31000   0.21000
   3.00000   3.00000   3.00000   3.00000   3.00000   3.00000   3.00000
  -6.00000  -6.00000  -6.00000  -4.00000  -4.00000  -4.00000  -4.00000
   9.00000   8.00000   8.50000   8.00000   8.00000   8.00000   9.00000
 -10.00000 -10.00000 -10.00000  -8.00000  -8.00000  -8.00000  -8.00000
  -3.00000  -3.00000  -3.00000  -2.00000  -1.00000  -1.00000  -3.00000
 125.00000 150.00000 150.00000 180.00000 180.00000 180.00000 150.00000
 150.00000 180.00000 180.00000 200.00000 200.00000 200.00000 180.00000
 180.00000 200.00000 200.00000 250.00000 250.00000 230.00000 195.00000
   0.10000 400.00000  50.000001000.00000 - Site #1 Initial Conditions
   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000 - PHYTM 1
 100.00000 100.00000 100.00000 100.00000   0.00000   0.00000  30.00000 - PHYTM 2
   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000 - PHYTM 3
  11.00000  11.00000  11.00000  25.00000   0.00000   0.00000   6.00000 - PHYTM 4
   0.20000 800.00000 100.000002000.00000 - Site #2 Initial Conditions
   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000 - PHYTM 1
   0.00000 100.00000 100.00000   0.00000 100.00000 100.00000  30.00000 - PHYTM 2
   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000 - PHYTM 3
   0.00000  11.00000  11.00000   0.00000  40.00000  40.00000   6.00000 - PHYTM 4
   0.01500   0.07000   0.00350  -0.02800   5.00000   2.20000 - Location
                                                                Parameters
....:....1....:....2....:....3....:....4....:....5....:....6....:....7....:....8
```

Figure 11.11
A representative plant parameter file for the simulation of seven plant species on two sites. (The first and last lines are rulers to aid in locating data by column and are not part of the output file.)

```
....:....1....:....2....:....3....:....4....:....5....:....6....:....7....:....8
   3
   250.0   100.0   250.0
      0.10      0.90
      0.01      0.01      0.01      0.01      0.01      0.01      0.01      0.01
      0.10      0.01      0.70      0.10     0.005     0.005
       1.0      90.0
      0.40      0.60
      0.16     0.005      0.16     0.005      0.16    0.0001     0.001     0.001
      0.01      0.01      0.39     0.001      0.10    0.0001
      91.0     335.0
      0.10      0.90
      0.01      0.01      0.01      0.01      0.01       0.01     0.01      0.01
      0.10      0.01      0.70      0.10     0.005      0.005
     336.0     365.0
       1.0       1.0       1.0
   430
00001
     450.0     115.0     161.0     365.0     250.0
       1.0      0.80     145.0     161.0
     0.209      0.01      0.35      0.01      0.35      0.01    0.0005    0.0025
    0.0005    0.0025      0.02    0.0025      0.03    0.0025
    0.50      0.50        0.65    0.65        0.80      0.80    0.30      0.0
    0.30      0.0         0.30    0.00        1.00      0.10
    0.5       0.5
    1.0       1.0
    1
     70.00     67.00     64.00     63.00     65.00
     12.00      6.00
....:....1....:....2....:....3....:....4....:....5....:....6....:....7....:....8
```

Figure 11.12
A representative animal parameter file for the simulation of 3 wildlife species and 430 steers grazing on two sites. (The first and last lines are rulers to aid in locating data by column and are not part of the output file.)

*** SIMULATION DEFINITION ***

FIRST YEAR: 1980 NUMBER OF YEARS: 1 FIRST MONTH: 1 FIRST DAY: 1 NUMBER OF SITES: 2
TOTAL FIELD AREA (AC): 3000.00 FIELD LATITUDE (DEGREES): 43.60
FIELD ELEVATION: 5500.00 TEMPERATURE ELEVATION: 5500.00

ENGLISH/METRIC CONVERSION SWITCH = 0, PRINT-SWITCH VALUES: IP1 = 0 IP2 = 1 IP3 = 0 IP4 = 0 IP5 = 0 IP6 = 0 IP7 = 1

++ SOILS INFORMATION ++

REPORT FOR SITE NO.	NO. SOIL LAYERS	AREA	COND.-I CURVE NO.	CROP FACTOR	ROOTING DEPTH	CRACK FACTOR
1	5	2400.0	65.00	0.500	16.000	0.000

SOIL-LAYER PARAMETERS

LAYER		1	2	3	4	5
SOIL POROSITY	(IN/IN):	0.400	0.400	0.400	0.400	0.300
SOIL WATER AT 0.3 BAR	(IN/IN):	0.270	0.270	0.270	0.330	0.250
SOIL WATER AT 15 BARS	(IN/IN):	0.095	0.095	0.095	0.130	0.150
SOIL WATER AT 50 BARS	(IN/IN):	0.068	0.068	0.068	0.097	0.128
SAT.-SOIL CONDUCTIVITY	(IN/HR):	0.500	0.050	0.050	0.001	0.750
ACCUMULATED SOIL DEPTH	(IN) :	3.000	6.000	16.000	32.000	44.000
MAXIMUM STORAGE	(IN) :	0.995	0.995	3.317	4.851	2.069
FIELD CAPACITY	(IN) :	0.605	0.605	2.017	3.731	1.469

REPORT FOR SITE NO.	NO. SOIL LAYERS	AREA	COND.-I CURVE NO.	CROP FACTOR	ROOTING DEPTH	CRACK FACTOR
2	6	600.0	60.00	0.500	50.000	0.000

SOIL-LAYER PARAMETERS

LAYER		1	2	3	4	5	6
SOIL POROSITY	(IN/IN):	0.500	0.500	0.500	0.500	0.480	0.440
SOIL WATER AT 0.3 BAR	(IN/IN):	0.382	0.382	0.382	0.382	0.390	0.283
SOIL WATER AT 15 BARS	(IN/IN):	0.134	0.134	0.134	0.134	0.150	0.091
SOIL WATER AT 50 BARS	(IN/IN):	0.096	0.096	0.096	0.096	0.110	0.064
SAT.-SOIL CONDUCTIVITY	(IN/HR):	0.500	0.500	0.500	0.500	0.025	1.000
ACCUMULATED SOIL DEPTH	(IN) :	3.000	6.000	8.000	13.000	50.000	63.000
MAXIMUM STORAGE	(IN) :	1.211	1.211	0.808	2.019	13.672	4.894
FIELD CAPACITY	(IN) :	0.857	0.857	0.572	1.429	10.342	2.853

++ SNOW ACCUMULATION AND MELT PARAMETERS ++

GAUGE-CATCH CORRECTION FACTOR 1.000
MAXIMUM-MELT FACTOR (MM/C*DAY) 5.00000
MINIMUM-MELT FACTOR (MM/C*DAY) 3.00000
WIND FUNCTION FOR RAIN-ON-SNOW PERIODS (MM/MB*DAY) 0.20000
WATER EQUIVALENT ABOVE WHICH THERE IS 100% SNOW COVER 800.00000
AREAL DEPLETION CURVE TYPE NUMBER 5.00
NEGATIVE MELT FACTOR (MM/C) 0.60000
ANTECEDENT-TEMPERATURE WEIGHT 0.90
TEMPERATURE FOR MELT DURING NONRAIN PERIODS (C) 0.00000
TEMPERATURE TO DIFFERENTIATE RAIN FROM SNOW (C) 0.00000
PERCENT LIQUID WATER IN SNOWPACK (DECIMAL)0.02
DAILY GROUNDMELT (MM/DAY) 0.30000

++ PLANT-COMPONENT INPUTS ++

NUMBER OF PLANT SPECIES = 7
NUMBER OF PARAMETERS PER PLANT SPECIES = 29
NUMBER OF CRITICAL VALUES PER PLANT SPECIES = 8

SPECIES 1 IS SANDBURGS BLUEGRASS (POA SANDBURGII)
SPECIES 2 IS BLUEGRASS - REGULAR (POA SP.)

SPECIES 3 IS IOAHO FESCUE (FESTUCA IDAHOENSIS)
SPECIES 4 IS LOW SAGE (ARTEMISIA ARBUSCULA)
SPECIES 5 IS BIG SAGE (ARTEMISIA TRIDENTATA)
SPECIES 6 IS BITTERBUSH (PURSHIA TRIOENTATA)
SPECIES 7 IS COOL-SEASON FORBS

SPECIES	1	2	3	4	5	6	7
PARAMETER 1	40.00000	40.00000	30.00000	11.00000	15.00000	20.00000	20.00000
PARAMETER 2	1.90000	2.00000	2.00000	2.00000	2.00000	2.10000	1.30000
PARAMETER 3	30.00000	30.00000	30.00000	35.00000	35.00000	35.00000	30.00000
PARAMETER 4	15.00000	15.00000	15.00000	15.00000	15.00000	15.00000	15.00000
PARAMETER 5	0.00000	0.00000	0.00000	2.00000	0.00000	0.00000	3.00000
PARAMETER 6	10.00000	9.00000	9.00000	12.00000	15.00000	15.00000	8.50000
PARAMETER 7	6.30000	6.40000	6.10000	5.70000	5.70000	5.70000	4.75000
PARAMETER 8	0.70000	0.70000	0.70000	0.70000	0.70000	0.70000	0.90000
PARAMETER 9	8.00000	8.00000	8.00000	10.00000	10.00000	10.00000	4.00000
PARAMETER 10	-0.00019	-0.00014	-0.00014	-0.00002	-0.00002	-0.00002	-0.00050
PARAMETER 11	-0.40000	-0.36000	-0.50000	-0.00025	-0.00030	-0.00027	-0.65000
PARAMETER 12	0.05000	0.05000	0.05000	0.00070	0.00050	0.00060	0.06000
PARAMETER 13	-0.00950	-0.00900	-0.00900	-0.00090	-0.00100	-0.00050	-0.01000
PARAMETER 14	-0.00500	-0.00500	-0.00500	0.00000	0.00000	0.00000	-0.00600
PARAMETER 15	0.00400	0.00400	0.00400	0.00050	0.00050	0.00050	0.00500
PARAMETER 16	0.02000	0.02000	0.02000	0.03000	0.03000	0.03000	0.03000
PARAMETER 17	0.01800	0.02000	0.01800	0.04000	0.03000	0.02000	0.05000
PARAMETER 18	0.00500	0.00500	0.00500	0.00500	0.00500	0.00500	0.00500
PARAMETER 19	0.01000	0.01000	0.01000	0.01000	0.01000	0.01000	0.00500
PARAMETER 20	25.00000	23.00000	17.00000	22.00000	19.00000	21.00000	8.00000
PARAMETER 21	0.06000	0.06000	0.06000	0.05000	0.05000	0.05000	0.05000
PARAMETER 22	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
PARAMETER 23	0.01000	0.01000	0.01000	0.01000	0.01000	0.01000	0.01000
PARAMETER 24	0.00250	0.00300	0.00270	0.00150	0.00150	0.00150	0.00150
PARAMETER 25	0.00400	0.00350	0.00250	0.00050	0.00050	0.00050	0.00100
PARAMETER 26	0.00900	0.00900	0.00900	0.01000	0.01000	0.01000	0.01100
PARAMETER 27	-117.00000	-120.00000	-115.00000	-127.00000	-128.00000	-130.00000	-110.00000
PARAMETER 28	0.00300	0.00200	0.00300	0.00100	0.00200	0.00150	0.00200
PARAMETER 29	0.42000	0.42000	0.42000	0.35000	0.31000	0.31000	0.21000
CRITICAL VALUE 1	3.00000	3.00000	3.00000	3.00000	3.00000	3.00000	3.00000
CRITICAL VALUE 2	-6.00000	-6.00000	-6.00000	-4.00000	-4.00000	-4.00000	-4.00000
CRITICAL VALUE 3	9.00000	8.00000	8.50000	8.00000	8.00000	8.00000	9.00000
CRITICAL VALUE 4	-10.00000	-10.00000	-10.00000	-8.00000	-8.00000	-8.00000	-8.00000
CRITICAL VALUE 5	-3.00000	-3.00000	-3.00000	-2.00000	-1.00000	-1.00000	-3.00000
CRITICAL VALUE 6	125.00000	150.00000	150.00000	180.00000	180.00000	180.00000	150.00000
CRITICAL VALUE 7	150.00000	180.00000	180.00000	200.00000	200.00000	200.00000	180.00000
CRITICAL VALUE 8	180.00000	200.00000	200.00000	250.00000	250.00000	230.00000	195.00000

SITE-NUMBER- 1 INITIAL CONOITIONS:

PLANT SPECIES	STANOING GREEN (C)	STANOING GREEN (N)	LIVE ROOTS (C)	LIVE ROOTS (N)	PROPAGULES (C)	PROPAGULES (N)	STANOING DEAD (C)	STANOING OEAO (N)
1	0.000	0.000	100.000	1.000	0.000	0.000	11.000	0.055
2	0.000	0.000	100.000	1.000	0.000	0.000	11.000	0.055
3	0.000	0.000	100.000	1.000	0.000	0.000	11.000	0.055
4	0.000	0.000	100.000	1.000	0.000	0.000	25.000	0.125
5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
6	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
7	0.000	0.000	30.000	0.300	0.000	0.000	6.000	0.030

NON-SPECIES-SPECIFIC INITIAL VALUES:

OEAO ROOTS (C)	OEAD ROOTS (N)	LITTER (C)	LITTER (N)	ORGANIC MATTER (C)	ORGANIC MATTER (N)	SOIL INORGANIC NITROGEN
400.000	2.400	50.000	0.500	1000.000	40.000	0.100

SITE-NUMBER- 2 INITIAL CONOITIONS:

PLANT SPECIES	STANOING GREEN (C)	STANOING GREEN (N)	LIVE ROOTS (C)	LIVE ROOTS (N)	PROPAGULES (C)	PROPAGULES (N)	STANOING OEAD (C)	STANOING OEAO (N)
1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2	0.000	0.000	100.000	1.000	0.000	0.000	11.000	0.055
3	0.000	0.000	100.000	1.000	0.000	0.000	11.000	0.055
4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5	0.000	0.000	100.000	1.000	0.000	0.000	40.000	0.200

6	0.000	0.000	100.000	1.000	0.000	0.000	40.000	0.200
7	0.000	0.000	30.000	0.300	0.000	0.000	6.000	0.030

NON-SPECIES-SPECIFIC INITIAL VALUES:

DEAD ROOTS (C)	DEAD ROOTS (N)	LITTER (C)	LITTER (N)	ORGANIC MATTER (C)	ORGANIC MATTER (N)	SOIL INORGANIC NITROGEN
800.000	4.800	100.000	1.000	2000.000	80.000	0.200

NON-SITE-, NON-SPECIES-SPECIFIC PARAMETERS:
0.015 0.070 0.004 -0.028 5.000 2.200

++ ANIMAL COMPONENT INPUTS ++

WILDLIFE SPECIES # 1 POPULATION = 250.
PREFERENCE FOR LOCATION 0.10 0.90
PREFERENCE FOR FORAGE (LIVE/DEAD) 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.010 0.100 0.010 0.700 0.100 0.005 0.005
DAY ENTER SITE 1. DAY OFF SITE 90.
DAILY DRY-MATTER DEMAND (KG/ANIMAL/HERD) 1.00

WILDLIFE SPECIES # 2 POPULATION = 100.
PREFERENCE FOR LOCATION 0.40 0.60
PREFERENCE FOR FORAGE (LIVE/DEAD) 0.159 0.005 0.159 0.005 0.159 0.000 0.001 0.001 0.010 0.010 0.389 0.001 0.100 0.000
DAY ENTER SITE 91. DAY OFF SITE 335.
DAILY DRY-MATTER DEMAND (KG/ANIMAL/HERD) 1.00

WILDLIFE SPECIES # 3 POPULATION = 250.
PREFERENCE FOR LOCATION 0.10 0.90
PREFERENCE FOR FORAGE (LIVE/DEAD) 0.001 0.001 0.001 0.001 0.001 0.000 0.911 0.001 0.009 0.001 0.064 0.009 0.000 0.000
DAY ENTER SITE 336. DAY OFF SITE 365.
DAILY DRY-MATTER DEMAND (KG/ANIMAL/HERD) 1.00

++ STEER-GROWTH-COMPONENT INPUTS ++

STEER HERD SIZE 430
STEER DIET SUPPLEMENTATION FLAG ON
AMOUNT OF SUPPLEMENT (KG/HD/DAY) 1.00000
DIGESTIBILITY OF THE SUPPLEMENT 0.800
DAY SUPPLEMENTATION STARTS 145.
DAY SUPPLEMENTATION STOPS 161.
AVERAGE STEER PARAMETERS
MEAN ASYMPTOTIC WEIGHT FOR MATURE STEER (KG) 450.00000
DAY STEER STARTS GRAZING 115.
DAY STEER STOPS GRAZING 161.
AGE OF STEER AT TIME GRAZING STARTS (DAYS) 365.00000
WEIGHT OF STEER AT TIME GRAZING STARTS (KG) 250.00000

SPECIES PREFERENCE

SPECIES	GREEN	DEAD
1	0.209	0.010
2	0.350	0.010
3	0.350	0.010
4	0.001	0.002
5	0.001	0.002
6	0.020	0.002
7	0.030	0.002

PHYSICAL LIMITATION

SPECIES	GREEN	DEAD
1	0.500	0.500
2	0.650	0.650
3	0.800	0.800
4	0.300	0.000
5	0.300	0.000
6	0.300	0.000
7	1.000	0.100

LOCATION PREFERENCE ANO LIMITATIONS

SITE	LOCATION	LIMITATION
1	0.500	1.000
2	0.500	1.000

++ ECONOMICS COMPONENT INPUTS ++

400-500 POUNO STEERS 0.7000 OOLLARS/POUNO
500-600 POUND STEERS 0.6700 DOLLARS/POUNO
600-700 POUNO STEERS 0.6400 DOLLARS/POUND
700-800 POUND STEERS 0.6300 DOLLARS/POUNO
800-1100 POUND STEERS 0.6500 OOLLARS/POUNO

DISCOUNT RATE = $12.0000 ANNUAL RATE

LIVESTOCK EXPENSES = $ 6.0000 /HEAD/MONTH

FIELD REPORT FOR YEAR 1980

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
PRECIPITATION (IN)	1.47	0.68	1.17	1.22	1.50	1.98	0.56	0.19	0.35	0.80	1.37	2.48	13.78
INFILTRATION (IN)	0.63	1.52	1.17	1.22	1.50	1.98	0.56	0.19	0.35	0.80	1.37	1.20	12.49
POTENTIAL ET (IN)	0.36	1.31	2.88	5.40	7.39	8.31	8.96	7.15	5.10	2.67	1.24	0.32	51.10
SOIL EVAPORATION (IN)	0.14	0.60	1.30	1.23	1.01	1.01	0.71	0.18	0.30	0.50	0.43	0.11	7.53
PLANT TRANSPIRATION (IN)	0.00	0.00	0.00	1.16	4.17	1.18	0.24	0.02	0.01	0.00	0.00	0.00	6.78
OEEP PERCOLATION (IN)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PLANT-AVAILABLE WATER (IN)	4.68	5.61	5.47	4.29	0.62	0.40	0.01	0.01	0.05	0.35	1.29	2.38	25.17
MONTHENO PLANT BIOMASS (KG/HA)	0.0	0.0	0.0	1422.8	1862.1	1584.5	730.7	289.0	49.8	2.8	0.4	0.0	
LIVESTOCK WT (KG)	0.0	0.0	0.0	254.8	270.5	276.5	0.0	0.0	0.0	0.0	0.0	0.0	26.5

*********** ECONOMICS REPORT FOR 1980***

STEER PURCHASE COST	ANNUAL VARIABLE COST	TOTAL ANNUAL COSTS	POUNDS OF BEEF SOLO	GROSS REVENUE	NET REVENUE	NET PRESENT VALUE
158786.31	9.20	158795.52	262157.59	167780.86	8985.34	8850.50

******* NET PRESENT VALUE 8850.50

SITE REPORT FOR SITE NUMBER 1 FOR YEAR 1980

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
PRECIPITATION (IN)	1.47	0.68	1.17	1.22	1.50	1.98	0.56	0.19	0.35	0.80	1.37	2.48	13.78
INFILTRATION (IN)	0.63	1.52	1.17	1.22	1.50	1.98	0.56	0.19	0.35	0.80	1.37	1.20	12.49
POTENTIAL ET (IN)	0.36	1.31	2.88	5.40	7.39	8.31	8.96	7.15	5.10	2.67	1.24	0.32	51.10
SOIL EVAPORATION (IN)	0.14	0.60	1.30	1.21	0.99	1.09	0.67	0.18	0.30	0.50	0.43	0.11	7.51
PLANT TRANSPIRATION (IN)	0.00	0.00	0.00	1.15	3.89	0.92	0.11	0.01	0.01	0.00	0.00	0.00	6.09
OEEP PERCOLATION (IN)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PLANT-AVAILABLE WATER (IN)	3.97	4.90	4.76	3.62	0.25	0.22	0.00	0.00	0.04	0.35	1.29	2.37	
MONTHENO PLANT BIOMASS (KG/HA)	0.0	0.0	0.0	735.7	821.0	643.9	229.4	89.0	17.4	1.4	0.2	0.0	

SITE REPORT FOR SITE NUMBER 2 FOR YEAR 1980

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
PRECIPITATION (IN)	1.47	0.68	1.17	1.22	1.50	1.98	0.56	0.19	0.35	0.80	1.37	2.48	13.78
INFILTRATION (IN)	0.63	1.53	1.17	1.22	1.50	1.98	0.56	0.19	0.35	0.80	1.37	1.20	12.50
POTENTIAL ET (IN)	0.36	1.31	2.88	5.40	7.39	8.31	8.96	7.15	5.10	2.67	1.24	0.32	51.10
SOIL EVAPORATION (IN)	0.14	0.60	1.30	1.34	1.11	0.69	0.89	0.18	0.30	0.50	0.43	0.11	7.61
PLANT TRANSPIRATION (IN)	0.00	0.00	0.00	1.21	5.30	2.23	0.74	0.04	0.01	0.00	0.00	0.00	9.52
DEEP PERCOLATION (IN)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PLANT-AVAILABLE WATER (IN)	7.52	8.45	8.31	6.98	2.08	1.14	0.07	0.03	0.08	0.38	1.32	2.40	
MONTHEND PLANT BIOMASS (KG/HA)	0.0	0.0	0.0	687.1	1041.2	940.7	501.3	200.0	32.3	1.3	0.2	0.0	

Figure 11.13
Simulation report generated by the field-scale version of SPUR for two sites and seven plant species with steer and wildlife grazing.

12. SAMPLE DATA SETS FOR THE BASIN-SCALE VERSION

E.P. Springer

INTRODUCTION

Example data sets are presented in this chapter for the basin-scale version of SPUR. The results of two example simulations are given so that users can compare this output with the output from their computers. As with the field-scale version, the comparable accuracy is determined by word representation and size and run-time-library algorithms used to compute the intrinsic functions contained in the SPUR code.

The organization of data for the basin-scale version of SPUR is given in chapter 3. The user must note the units of the parameters and initial conditions for the proper operation of the computer code. This information is contained in tables 3.3, 3.4, and 3.5 of chapter 3.

The weather data required by the basin-scale version of SPUR is the same as that used by the field-scale version except that precipitation can be spatially distributed over the fields of a watershed if more than one precipitation gauge is available. The user can use the information in chapters 4 and 10 to generate a weather file.

EXAMPLE NO. 1 - THREE FIELDS, ONE CHANNEL, SEVEN PLANT SPECIES, STEER AND WILDLIFE GRAZING

Example No. 1 is a first-order watershed located in the northwestern United States. A characteristic of this region is the formation of snowdrifts on the north-facing slopes with associated deep soils and shallow soils on the windswept south-facing slopes.

The Climate File

The weather data were generated using the file shown in figure 12.1. Figure 12.2 contains the first 15 lines of the generated weather data file; precipitation is in inches, the maximum and minimum air temperatures are in degrees Fahrenheit, solar radiation is in langleys, and wind run is in kilometers per day.

The Simulation Control, Soils, and Hydrology File

Figure 12.3 is the simulation control, soils, and hydrology data file for Example No. 1. This is a simulation that begins on day 1 of month 1 in 1970, and the simulation period is 1 year. The watershed area is approximately 0.1 mi^2 and the watershed contains a single channel. The print flag for monthly/annual results is the only operational output feature. The basin-wide hydrograph parameters (record no. 4 in fig. 12.3) are used only for rainfall-generated runoff.

Channel 1 has no input channels and its watershed consists of three fields. The channel has cut to bedrock, so it is assumed that transmission losses are not occurring and the channel hydraulic conductivity is set to zero. There are eight sediment particle-sized classes in the channel bed material, and the fraction of silt and clay in the bed material is 0.10.

The differences between the north- and south-facing slopes are seen in the inputs for fields 1 and 2. Field 1 has five soil layers, and the soil profile extends to 63 in. The soil profile for field 2 is 30 inches in total depth. Other differences in the two fields are reflected in the values for condition-I curve number, return-flow time, aspect, USLE cover factor, and root depth. Field 3 is an upland field (CITFLD=0), and its inputs are the same as those for field 1.

The snow accumulation and melt parameters are essentially the same for all fields except the value for SI on field 2, which is smaller to reflect the lower vegetation density on the south-facing slope. There was no snow water equivalent on the watershed at the beginning of the simulation.

The Plant-Component File

Seven plant species were assumed to be present on the watershed. Each plant species or functional group is characterized by 29 parameters and 8 critical values. Differences in plant response are attained by manipulating these parameters and critical values. Figure 12.4 is the plant-component input file for Example No. 1.

The initial conditions for the plant species are entered by fields in the same order as the fields are ordered in the hydrology input file. This is an important fact to remember because the identification number given to a field does not necessarily match the input order for that field. Another difference between fields 1 and 2 is the absence of species 2 on field 2 reflected by the zero value for live roots (PHYTM 2). The starting date for Example No. 1 is January 1 so the aboveground green phytomass for all species is set to zero. The standing dead material (PHYTM 4) for the shrub species includes the woody material.

The Animal-Component File

Figure 12.5 is the animal-component data file for Example No. 1. A single member of a wildlife species is present for the entire year. This wildlife species has equal preference for fields 1 and 3. Also, the wildlife species has equal preference for the standing live phytomass of plant species 1, 2, and 3, and the animal has a daily intake rate of 0.5 kg per day.

Two steers graze the watershed between Julian days 130 to 160. The steer's diets are not supplemented and each weighs 250 kg at grazing initiation. The steers have a marked preference for the grass and forb species over the shrubs, and the steers prefer fields 1 and 3 over field 2.

The economics report is requested. Prices per 100

```
....:....1....:....2....:....3....:....4....:....5....:....6....:....7....:....8
 SPUR BASIN SCALE EXAMPLE 1
    1    0    0    0    1 1970    1    1     43.60
 000000387 000000919 000000239 000000673
 0.584 0.530 0.497 0.404 0.496 0.492 0.406 0.466 0.443 0.465 0.570 0.500
 0.258 0.234 0.268 0.255 0.193 0.185 0.086 0.090 0.112 0.162 0.235 0.302
 0.838 0.998 0.998 0.785 0.919 0.991 0.998 0.883 0.852 0.886 0.938 0.997
 0.163 0.106 0.126 0.200 0.142 0.170 0.095 0.158 0.192 0.177 0.139 0.131
    54.9     23.0    0.183    -.087
   49.95
    38.1     16.9    0.243    -.115
   430.0   285.0
   280.0
     9.3     5.4
  9.00 10.00 11.00 10.00 10.00  9.00  9.00  8.00  9.00  9.00  9.00  9.00
....:....1....:....2....:....3....:....4....:....5....:....6....:....7....:....8
```

Figure 12.1
The parameter file used to generate the weather sequence for Example No. 1 using the basin-scale version of SPUR. (The first and last lines are rulers to aid in locating data by column and are not part of the data file.)

Day	Precip. (in)	Max. temp. (°F)	Min. temp. (°F)	Solar rad. (langley)	Wind run (m/h)
....:....1....:....2....:....3....:....4....:....5....:....6....:....7....:....8					
1	0.00000	28.60810	24.43053	60.27975	170.93892
2	0.00000	21.70808	21.70808	116.40603	201.17661
3	0.00000	18.02981	18.02981	46.86095	251.61920
4	0.00000	23.38228	18.18587	181.94937	600.72217
5	0.00000	34.46822	17.19365	224.49380	397.23447
6	0.00000	38.31576	23.77810	225.94254	58.28588
7	0.00000	33.52345	18.91720	227.47600	258.67874
8	0.00000	32.66536	22.59432	187.66380	387.39233
9	0.00000	31.33573	26.10799	169.73798	670.85944
10	0.00000	33.56145	26.78422	143.34299	313.76974
11	0.00000	34.97777	30.52710	163.80537	153.88715
12	0.00000	33.79710	25.17295	103.81207	303.46661
13	0.00000	32.84413	25.36897	118.86399	568.29211
14	0.00000	36.41470	14.89460	162.21654	232.34831
15	0.18734	30.17189	20.72690	48.55307	243.25209
....:....1....:....2....:....3....:....4....:....5....:....6....:....7....:....8					

Figure 12.2
The first 15 lines of the weather file used in Example No. 1 for the basin-scale version of SPUR. (The first and last lines are rulers to aid in locating data by column and are not part of the data file.)

lb. for the five sized classes are $70.00, $67.00, $64.00, $63.00, and $65.00. The current discount rate is 12 percent and the costs total $6.00 per steer per month.

Results for Example No. 1

The only operational report flag for this example is the monthly/annual report. A channel report, a report for each field, a livestock report, and an economics report are generated. The report is shown in figure 12.6.

EXAMPLE NO. 2 - FIVE FIELDS, TWO CHANNELS, FIVE PLANT SPECIES

This example was designed to show a data set for a multiple-channel system. The hydrology and soils information was obtained from an example presented by Renard et al. (1983).

The Climate File

Figure 12.7 is the parameter file used to generate the weather sequence for Example No. 2. A single

```
....:....1....:....2....:....3....:....4....:....5....:....6....:....7....:....8
 SPUR BASIN SCALE TEST EXAMPLE 1
 1970    1    1    1    0.0990   01 0 0 0 0 0 1
 (11X,5F10.5)
     17.00       0.30     0.0275      0.10      0.042
   1    0    0    3    1      .3300     2.0000    2.0000    0.0000
   8     .1800     .1000     .1200     0.2800     .1000    5.0000
  .1065     .200     .375      .75      1.50      3.50     7.50     12.5
  .3300     .200     .190     .150       .01       .01     .005     .005
   0    0    0.0000    0.0000    0.0000    0.0000
   1    1    5    1   25.4300   55.0000   40.0000
    .2800     .0300    1.0000   7.00000   40.0000    0.2500    0.0000      .18
   1.0000    0.9000    0.5000
    .5000     .5000     .5000     .4800     .4400
    .3820     .3820     .2990     .3110     .2830
    .1340     .1340     .1500     .1260     .0910
    .5000     .5000     .2500     .0100    1.0000
  11.0000   11.0000   10.0000    8.0000   23.0000
   2    1    3    2   22.260    65.0000   35.0000
    .2800     .0100    1.0000    7.0000   19.0000    0.2500  180.0000      .18
   0.0000    0.5000    0.5000
    .4480     .4770     .4620
    .3420     .3140     .3670
    .1300     .1310     .1300
    .2500     .2500     .1000
   6.0000   13.0000   11.0000
   3    0    5    3   15.700    55.0000   40.0000
    .2800     .0300    1.0000    7.0000   40.0000    0.2500  270.0000      .18
   0.0000    0.9000    0.5000
    .5000     .5000     .5000     .4800     .4400
    .3820     .3820     .2990     .3110     .2830
    .1340     .1340     .1500     .1260     .0910
    .5000     .5000     .2500     .0100    1.0000
  11.0000   11.0000   10.0000    8.0000   23.0000
    43.60   6600.00   6600.00
    1.000     5.000     3.000     0.200   800.000     5.000     0.500     0.900
    0.000     0.000     0.020     0.300
    0.000
    1.000     5.000     3.000     0.200   500.000     5.000     0.600     0.909
    0.000     0.000     0.020     0.300
    0.000
    1.000     5.000     3.000     0.200   800.000     5.000     0.500     0.900
    0.000     0.000     0.020     0.300
    0.000
....:....1....:....2....:....3....:....4....:....5....:....6....:....7....:....8
```

Figure 12.3
The simulation control, hydrology and soils data file for Example No. 1 using the basin-scale version of SPUR. A single channel with three fields is simulated. (The first and last lines are rulers to aid in locating data by column and are not part of the data file.)

year of weather data was generated. The location is at 32° north latitude and is representative of the Southwestern United States near Tombstone, Arizona.

The first 15 lines of the generated weather sequence are given in figure 12.8. The output variables have the same units as they had in Example No. 1.

The Simulation Control, Soils, and Hydrology File

The file for this example is given in figure 12.9. The starting year for the simulation is 1962, and the simulation begins on day 1 of month 1. Only a single year is simulated. Two channels are in this example, and the monthly/annual report is requested.

The basin hydrograph parameters were taken from the Lucky Hills watershed simulation conducted by Renard et al. (1983).

Channel 1 has no input channels and its watershed consists of three fields. A report for this sub-basin is requested. The watershed is located in a region where alluvial channels are present so channel transmission losses are possible. The

```
....:....1....:....2....:....3....:....4....:....5....:....6....:....7....:....8
   7   29    8
    BLUEGRASS
    BLUEBUNCH WHEATGRASS
    IDAHO FESCUE
    LOW SAGEBRUSH
    BIG SAGEBRUSH
    BITTERBRUSH
    COOL SEASON FORBS
  40.00000  25.00000  30.00000  11.00000  15.00000  20.00000  20.00000
   1.90000   2.00000   2.00000   2.00000   2.00000   2.10000   1.30000
  30.00000  35.00000  30.00000  35.00000  35.00000  35.00000  30.00000
  15.00000  20.00000  15.00000  15.00000  15.00000  15.00000  15.00000
   0.00000   3.00000   0.00000   2.00000   0.00000   0.00000   3.00000
  10.00000  10.00000   9.00000  12.00000  15.00000  15.00000   8.50000
   6.30000   6.29000   6.10000   5.70000   5.70000   5.70000   4.75000
   0.70000   0.70000   0.70000   0.70000   0.70000   0.70000   0.90000
   8.00000   8.00000   8.00000  10.00000  10.00000  10.00000   4.00000
  -0.00019  -0.00020  -0.00014  -0.00002  -0.00002  -0.00002  -0.00050
  -0.40000  -0.40000  -0.50000  -0.00025  -0.00030  -0.00027  -0.65000
   0.05000   0.05000   0.05000   0.00070   0.00050   0.00060   0.06000
  -0.00950  -0.01000  -0.00900  -0.00090  -0.00100  -0.00050  -0.01000
  -0.00500  -0.00600  -0.00500   0.00000   0.00000   0.00000  -0.00600
   0.00400   0.00400   0.00400   0.00050   0.00050   0.00050   0.00500
   0.02000   0.02000   0.02000   0.03000   0.03000   0.03000   0.03000
   0.01800   0.02000   0.01800   0.04000   0.03000   0.02000   0.05000
   0.00500   0.00500   0.00500   0.00500   0.00500   0.00500   0.00500
   0.01000   0.01000   0.01000   0.01000   0.01000   0.01000   0.00500
  25.00000  72.00000  17.00000  22.00000  19.00000  21.00000   8.00000
   0.06000   0.06000   0.06000   0.05000   0.05000   0.05000   0.05000
   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000
   0.01000   0.01000   0.01000   0.01000   0.01000   0.01000   0.01000
   0.00250   0.00250   0.00270   0.00150   0.00150   0.00150   0.00150
   0.00400   0.00400   0.00250   0.00050   0.00050   0.00050   0.00100
   0.00900   0.00900   0.00900   0.01000   0.01000   0.01000   0.01100
-117.00000-115.00000-115.00000-127.00000-128.00000-130.00000-110.00000
   0.00300   0.00300   0.00300   0.00100   0.00200   0.00150   0.00200
   0.42000   0.42000   0.42000   0.35000   0.31000   0.31000   0.21000
   3.00000   3.00000   3.00000   3.00000   3.00000   3.00000   3.00000
  -6.00000  -6.00000  -6.00000  -4.00000  -4.00000  -4.00000  -4.00000
   9.00000   8.50000   8.00000   8.00000   8.00000   8.00000   9.00000
 -10.00000 -10.00000 -10.00000  -8.00000  -8.00000  -8.00000  -8.00000
  -3.00000  -3.00000  -3.00000  -2.00000  -1.00000  -1.00000  -3.00000
 125.00000 150.00000 150.00000 180.00000 180.00000 180.00000 150.00000
 150.00000 165.00000 180.00000 200.00000 200.00000 200.00000 180.00000
 180.00000 195.00000 200.00000 250.00000 250.00000 230.00000 195.00000
   0.20000 800.00000 200.000002000.00000
   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000
 100.00000 250.00000 100.00000  50.00000  75.00000  50.00000  40.00000
   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000
   5.00000  11.00000   3.00000  40.00000  30.00000  30.00000   5.00000
   0.01000 500.00000 120.000001200.00000
   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000
 150.00000  00.00000  75.00000  75.00000  45.00000  40.00000  10.00000
   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000
   8.00000   0.00000   5.00000  75.00000  30.00000  20.00000   2.00000
   0.20000 800.00000 200.000002000.00000
   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000
 100.00000 250.00000 100.00000  50.00000  75.00000  50.00000  40.00000
   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000
   5.00000  11.00000   3.00000  40.00000  30.00000  30.00000   5.00000
   0.01500   0.07000   0.00350  -0.02800   5.00000   2.20000
....:....1....:....2....:....3....:....4....:....5....:....6....:....7....:....8
```

Figure 12.4
The plant component file used in Example No. 1 for the basin-scale version of SPUR. Seven plant species on three fields are simulated. (The first and last lines are rulers to aid in locating data by column and are not part of the data file.)

```
....:....1....:....2....:....3....:....4....:....5....:....6....:....7....:....8
    1
     1.0
      0.45      0.10      0.45
      0.25      0.02      0.25      0.02      0.25      0.02      0.01     0.005
      0.01      0.005     0.01      0.005     0.13      0.015
      1.00    365.00
      0.50
    2
00000
  455.    130.       160.       365.       250.
      0.22      0.01      0.30      0.01      0.24      0.01      0.001    0.0005
     0.001    0.0005     0.001    0.0005     0.189    0.0165
      0.50      0.50      0.75      0.75      0.50      0.50      0.30      0.30
      0.30      0.30      0.30      0.30      0.50      0.35
      0.45      0.10      0.45
      1.00      1.00      1.00
 1
     70.00     67.00     64.00     63.00     65.00
     12.00      6.00
....:....1....:....2....:....3....:....4....:....5....:....6....:....7....:....8
```

Figure 12.5
Animal parameter file used in Example No. 1 with the basin-scale version of SPUR. A single wildlife species with a population size of one and two steers are grazing on a watershed composed of three fields. (The first and last lines are rulers to aid in locating data by column and are not part of the data file.)

saturated hydraulic conductivity of the bed material is 2.0 inches per hour. There are eight sediment particle-sized classes in the bed material. The median particle diameter of the bed material is 0.57 mm, and the fraction of silt and clay in the bed is 0.035.

Records 7 and 8 are the median particle diameter for a sediment-sized class and the fraction of bed material found in that diameter class. No ponds are in this channel system (record 9).

Fields 1, 2, and 3 are located in the subbasin associated with channel 1. Field 1 is an upland field and fields 2 and 3 are lateral fields. All three fields have eight soil layers, and a separate report is generated for each. The long return-flow times, the 22.5-in rooting depth, and the zero-saturated hydraulic conductivity of the seventh soil layer indicate a dense layer in the soil profile at this depth. Essentially return flow does not occur on these watersheds.

The variables for channel system 2 begin on record 34. An upstream input channel, channel 1, is indicated. There are two fields comprising subbasin 2, and a subbasin report is requested. The saturated hydraulic conductivity of the bed material is 2.0 inches per hour. There are eight particle-sized classes of bed material, but the median particle size has increased to 0.74 mm from 0.57 mm in channel 1. Also, the fraction of silt and clay has decreased from channel 1. Again, no ponds are present in this channel system.

Fields 4 and 5 are both lateral fields and have the same properties as the previous three fields.

The snow accumulation and melt parameters are included despite the low potential for snowfall. The possibility of snow was decreased even further by setting the parameter PXTEMP to -2.0 °C. The parameter PXTEMP differentiates rain from snow based on the average daily air temperature.

The Plant-Component File

The five plant species in this example are listed as functional groups. The initial conditions are the same for each site. The plant-component input file is given in figure 12.10.

The Animal-Component File

Wildlife and domestic animals were assumed not to be present on this watershed. An animal-component input file is required with two records, each containing a zero in column five. For simplicity, this file is not shown.

Results for Example No. 2

The monthly/annual report file is shown in figure 12.11. A report was produced for each subbasin and field.

LITERATURE CITED

Renard, K.G., E.D. Shirley, J.R. Williams, and A.D. Nicks. 1983. SPUR hydrology component: Upland phases, p. 17-44. In J. R. Wight (ed.), SPUR--Simulation of Production and Utilization of Rangelands: A rangeland model for management and research. U.S. Department of Agriculture, Miscellaneous Publication 1431, 120 p.

FIRST YEAR: 1970 NUMBER OF YEARS: 1 FIRST MONTH: 1 FIRST DAY: 1
TOTAL BASIN AREA (SQUARE KILOMETERS): 0.0990 NUMBER OF CHANNELS: 1 DISTRIBUTED PRECIPITATION SWITCH: 0
ENGLISH/METRIC CONVERSION SWITCH = 0 PRINT SWITCH VALUES: IP1 = 0 IP2 = 0 IP3 = 1

MEAN RUNOFF DURATION COEFFICIENTS: 17.0000 0.3000
MEAN RUNOFF VOLUME COEFFICIENTS : 0.0275 -0.1000
MEAN RUNOFF PEAK RATE COEFFICIENT: 0.0420

****

CHAN ID	POND ID	NO. OF FIELDS	CHANNEL LINKAGE IN 1	IN 2	OUT	REPORT NOS. CHAN	POND	CHANNEL DIMENSIONS LENGTH (MI)	WIDTH (FT)	OUTLET (FT)	TRANSMISSION LOSS COEFFS. AXW (AC/FT)	BXW	FXW (MI)	HYDRL. CONDUCTIVITY CHANNEL (IN/HR)	POND (IN/HR)
1	0	3	0	0	0	1	0	0.33	2.00	2.00	0.00000	1.00000	0.33000	0.000	0.000

POND AREA (AC)	POND VOLUMES INIT. (AC-FT)	FULL (AC-FT)	CHANNEL SUBBASIN PARAMETERS MEAN DUR (HR)	MEAN VOL (AC-FT	MEAN PEAK (IN/HR)	AREA (AC)	CHANNEL SLOPE	ROUGHNESS TOTAL	WALL (SEC/FT**(1/3))	MEDIAN DIAMETER (MM)	FRACTION SILT & CLAY	CAS (SEC/FT)
0.000	0.0000	0.0000	8.4957	0.1831	0.0002	63.390	0.1800	0.1000	0.1200	0.2800	0.1000	5.0000

PARTICLE CLASS	DIAMETER (MM)	FRACTION IN BED
1	0.1065	0.3300
2	0.2000	0.2000
3	0.3750	0.1900
4	0.7500	0.1500
5	1.5000	0.0100
6	3.5000	0.0100
7	7.5000	0.0050
8	12.5000	0.0050

FIELD ID	FIELD TYPE	FIELD REPORT NO.	# SOIL LAYERS	FIELD AREA (AC)	CURVE NUMBER	RETURN FLOW TIME (DAY)	MODIFIED USLE FACTORS FOR FIELD SOIL	COVER	CONTROL	SL
1	LATERAL	1	5	25.430	55.00	40.00	0.28	0.03	1.00	7.00

SOIL LAYER PARAMETERS

	1 LAYER	2 LAYER	3 LAYER	4 LAYER	5 LAYER
SOIL POROSITY (IN/IN):	0.500	0.500	0.500	0.480	0.440
WATER AT .3 BAR (IN/IN):	0.382	0.382	0.299	0.311	0.283
WATER AT 15 BAR (IN/IN):	0.134	0.134	0.150	0.126	0.091
SATURATED COND. (IN/HR):	0.500	0.500	0.250	0.010	1.000
SOIL DEPTH, ACC. (IN):	11.000	22.000	32.000	40.000	63.000
FIELD CAPACITY (IN):	3.144	3.144	1.784	1.731	5.047
MAXIMUM STORAGE (IN):	4.442	4.442	3.794	3.083	8.658

FIELD ID	FIELD TYPE	FIELD REPORT NO.	# SOIL LAYERS	FIELD AREA (AC)	CURVE NUMBER	RETURN FLOW TIME (DAY)	MODIFIED USLE FACTORS FOR FIELD SOIL	COVER	CONTROL	SL
2	LATERAL	2	3	22.260	65.00	35.00	0.28	0.01	1.00	7.00

SOIL LAYER PARAMETERS

	1 LAYER	2 LAYER	3 LAYER
SOIL POROSITY (IN/IN):	0.448	0.477	0.462
WATER AT .3 BAR (IN/IN):	0.342	0.314	0.367
WATER AT 15 BAR (IN/IN):	0.130	0.131	0.130
SATURATED COND. (IN/HR):	0.250	0.250	0.100
SOIL DEPTH, ACC. (IN):	6.000	19.000	30.000
FIELD CAPACITY (IN):	1.478	2.790	3.007
MAXIMUM STORAGE (IN):	2.114	4.909	4.052

FIELD ID	FIELD TYPE	FIELD REPORT NO.	# SOIL LAYERS	FIELD AREA (AC)	CURVE NUMBER	RETURN FLOW TIME (DAY)	MODIFIED USLE FACTORS FOR FIELD SOIL	COVER	CONTROL	SL
3	UPLAND	3	5	15.700	55.00	40.00	0.28	0.03	1.00	7.00

SOIL LAYER PARAMETERS

	1 LAYER	2 LAYER	3 LAYER	4 LAYER	5 LAYER
SOIL POROSITY (IN/IN):	0.500	0.500	0.500	0.480	0.440
WATER AT .3 BAR (IN/IN):	0.382	0.382	0.299	0.311	0.283
WATER AT 15 BAR (IN/IN):	0.134	0.134	0.150	0.126	0.091
SATURATED COND. (IN/HR):	0.500	0.500	0.250	0.010	1.000
SOIL DEPTH, ACC. (IN):	11.000	22.000	32.000	40.000	63.000
FIELD CAPACITY (IN):	3.144	3.144	1.784	1.731	5.047
MAXIMUM STORAGE (IN):	4.442	4.442	3.794	3.083	8.658

++ PLANT COMPONENT INPUTS ++

NUMBER OF PLANT SPECIES = 7
NUMBER OF PARAMETERS PER PLANT SPECIES = 29
NUMBER OF CRITICAL VALUES PER PLANT SPECIES = 8

SPECIES 1 IS BLUEGRASS
SPECIES 2 IS BLUEBUNCH WHEATGRASS
SPECIES 3 IS IDAHO FESCUE
SPECIES 4 IS LOW SAGEBRUSH
SPECIES 5 IS BIG SAGEBRUSH
SPECIES 6 IS BITTERBRUSH
SPECIES 7 IS COOL SEASON FORBS

SPECIES	1	2	3	4	5	6	7
PARAMETER 1	40.00000	25.00000	30.00000	11.00000	15.00000	20.00000	20.00000
PARAMETER 2	1.90000	2.00000	2.00000	2.00000	2.00000	2.10000	1.30000
PARAMETER 3	30.00000	35.00000	30.00000	35.00000	35.00000	35.00000	30.00000
PARAMETER 4	15.00000	20.00000	15.00000	15.00000	15.00000	15.00000	15.00000
PARAMETER 5	0.00000	3.00000	0.00000	2.00000	0.00000	0.00000	3.00000
PARAMETER 6	10.00000	10.00000	9.00000	12.00000	15.00000	15.00000	8.50000
PARAMETER 7	6.30000	6.29000	6.10000	5.70000	5.70000	5.70000	4.75000
PARAMETER 8	0.70000	0.70000	0.70000	0.70000	0.70000	0.70000	0.90000
PARAMETER 9	8.00000	8.00000	8.00000	10.00000	10.00000	10.00000	4.00000
PARAMETER 10	-0.00019	-0.00020	-0.00014	-0.00002	-0.00002	-0.00002	-0.00050
PARAMETER 11	-0.40000	-0.40000	-0.50000	-0.00025	-0.00030	-0.00027	-0.65000
PARAMETER 12	0.05000	0.05000	0.05000	0.00070	0.00050	0.00060	0.06000
PARAMETER 13	-0.00950	-0.01000	-0.00900	-0.00090	-0.00100	-0.00050	-0.01000
PARAMETER 14	-0.00500	-0.00600	-0.00500	0.00000	0.00000	0.00000	-0.00600
PARAMETER 15	0.00400	0.00400	0.00400	0.00050	0.00050	0.00050	0.00500
PARAMETER 16	0.02000	0.02000	0.02000	0.03000	0.03000	0.03000	0.03000
PARAMETER 17	0.01800	0.02000	0.01800	0.04000	0.03000	0.02000	0.05000
PARAMETER 18	0.00500	0.00500	0.00500	0.00500	0.00500	0.00500	0.00500
PARAMETER 19	0.01000	0.01000	0.01000	0.01000	0.01000	0.01000	0.00500
PARAMETER 20	25.00000	72.00000	17.00000	22.00000	19.00000	21.00000	8.00000
PARAMETER 21	0.06000	0.06000	0.06000	0.05000	0.05000	0.05000	0.05000
PARAMETER 22	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
PARAMETER 23	0.01000	0.01000	0.01000	0.01000	0.01000	0.01000	0.01000
PARAMETER 24	0.00250	0.00250	0.00270	0.00150	0.00150	0.00150	0.00150
PARAMETER 25	0.00400	0.00400	0.00250	0.00050	0.00050	0.00050	0.00100
PARAMETER 26	0.00900	0.00900	0.00900	0.01000	0.01000	0.01000	0.01100
PARAMETER 27	-117.00000	-115.00000	-115.00000	-127.00000	-128.00000	-130.00000	-110.00000
PARAMETER 28	0.00300	0.00300	0.00300	0.00100	0.00200	0.00150	0.00200
PARAMETER 29	0.42000	0.42000	0.42000	0.35000	0.31000	0.31000	0.21000
CRITICAL VALUE 1	3.00000	3.00000	3.00000	3.00000	3.00000	3.00000	3.00000
CRITICAL VALUE 2	-6.00000	-6.00000	-6.00000	-4.00000	-4.00000	-4.00000	-4.00000
CRITICAL VALUE 3	9.00000	8.50000	8.00000	8.00000	8.00000	8.00000	9.00000
CRITICAL VALUE 4	-10.00000	-10.00000	-10.00000	-8.00000	-8.00000	-8.00000	-8.00000
CRITICAL VALUE 5	-3.00000	-3.00000	-3.00000	-2.00000	-1.00000	-1.00000	-3.00000
CRITICAL VALUE 6	125.00000	150.00000	150.00000	180.00000	180.00000	180.00000	150.00000
CRITICAL VALUE 7	150.00000	165.00000	180.00000	200.00000	200.00000	200.00000	180.00000
CRITICAL VALUE 8	180.00000	195.00000	200.00000	250.00000	250.00000	230.00000	195.00000

FIELD NUMBER 1 INITIAL CONDITIONS:

PLANT SPECIES	STANDING GREEN (C)	STANDING GREEN (N)	LIVE ROOTS (C)	LIVE ROOTS (N)	PROPAGULES (C)	PROPAGULES (N)	STANDING DEAD (C)	STANDING DEAD(N)
1	0.000	0.000	100.000	1.000	0.000	0.000	5.000	0.025
2	0.000	0.000	250.000	2.500	0.000	0.000	11.000	0.055
3	0.000	0.000	100.000	1.000	0.000	0.000	3.000	0.015
4	0.000	0.000	50.000	0.500	0.000	0.000	40.000	0.200
5	0.000	0.000	75.000	0.750	0.000	0.000	30.000	0.150
6	0.000	0.000	50.000	0.500	0.000	0.000	30.000	0.150
7	0.000	0.000	40.000	0.400	0.000	0.000	5.000	0.025

NONSPECIES SPECIFIC INITIAL VALUES:

DEAD ROOTS (C)	DEAD ROOTS (N)	LITTER (C)	LITTER (N)	ORGANIC MATTER (C)	ORGANIC MATTER (N)	SOIL INORGANIC NITROGEN
800.000	4.800	200.000	2.000	2000.000	80.000	0.200

FIELD NUMBER 2 INITIAL CONDITIONS:

PLANT SPECIES	STANDING GREEN (C)	STANDING GREEN (N)	LIVE ROOTS (C)	LIVE ROOTS (N)	PROPAGULES (C)	PROPAGULES (N)	STANDING DEAD (C)	STANDING DEAD(N)
1	0.000	0.000	150.000	1.500	0.000	0.000	8.000	0.040
2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3	0.000	0.000	75.000	0.750	0.000	0.000	5.000	0.025
4	0.000	0.000	75.000	0.750	0.000	0.000	75.000	0.375
5	0.000	0.000	45.000	0.450	0.000	0.000	30.000	0.150
6	0.000	0.000	40.000	0.400	0.000	0.000	20.000	0.100
7	0.000	0.000	10.000	0.100	0.000	0.000	2.000	0.010

NONSPECIES SPECIFIC INITIAL VALUES:

DEAD ROOTS (C)	DEAD ROOTS (N)	LITTER (C)	LITTER (N)	ORGANIC MATTER (C)	ORGANIC MATTER (N)	SOIL INORGANIC NITROGEN
500.000	3.000	120.000	1.200	1200.000	48.000	0.010

FIELD NUMBER 3 INITIAL CONDITIONS:

PLANT SPECIES	STANDING GREEN (C)	STANDING GREEN (N)	LIVE ROOTS (C)	LIVE ROOTS (N)	PROPAGULES (C)	PROPAGULES (N)	STANDING DEAD (C)	STANDING DEAD(N)
1	0.000	0.000	100.000	1.000	0.000	0.000	5.000	0.025
2	0.000	0.000	250.000	2.500	0.000	0.000	11.000	0.055
3	0.000	0.000	100.000	1.000	0.000	0.000	3.000	0.015
4	0.000	0.000	50.000	0.500	0.000	0.000	40.000	0.200
5	0.000	0.000	75.000	0.750	0.000	0.000	30.000	0.150
6	0.000	0.000	50.000	0.500	0.000	0.000	30.000	0.150
7	0.000	0.000	40.000	0.400	0.000	0.000	5.000	0.025

NONSPECIES SPECIFIC INITIAL VALUES:

DEAD ROOTS (C)	DEAD ROOTS (N)	LITTER (C)	LITTER (N)	ORGANIC MATTER (C)	ORGANIC MATTER (N)	SOIL INORGANIC NITROGEN
800.000	4.800	200.000	2.000	2000.000	80.000	0.200

NONSITE-NONSPECIES SPECIFIC PARAMETERS:

0.015	0.070	0.004	-0.028	5.000	2.200

++ ANIMAL COMPONENT INPUTS ++

SPECIES # 1 POPULATION 1.
PREFERENCE FOR LOCATION 0.45 0.10 0.45
PREFERENCE FOR FORAGE(LIVE/DEAO) 0.250 0.020 0.250 0.020 0.250 0.020 0.010 0.005 0.010 0.005 0.010 0.005 0.130 0.015
DAY ENTER SITE 1. OAY OFF SITE 365.
DAILY DRY MATTER OEMANO 0.50

*** LIVESTOCK INPUTS ***

TOTAL HERO SIZE 2

*** FOR THE AVERAGE STEER ***
MEAN ASYMPTOTIC WEIGHT FOR MATURE STEER IN THE SAME HERO (KG) 455.00000
OAY STEER STARTS GRAZING 130.
DAY STEER STOPS GRAZING 160.
AGE OF STEER AT TIME GRAZING STARTS (DAYS) 365.00000
WEIGHT OF STEER AT TIME GRAZING STARTS (KG) 250.00000

SPECIES PREFERENCE

SPECIES	GREEN	DRY
1	0.220	0.010
2	0.300	0.010
3	0.240	0.010
4	0.001	0.000
5	0.001	0.000
6	0.001	0.000
7	0.189	0.016

PHYSICAL LIMTATION

SPECIES	GREEN	ORY
1	0.500	0.500
2	0.750	0.750
3	0.500	0.500
4	0.300	0.300
5	0.300	0.300
6	0.300	0.300
7	0.500	0.350

LOCATION PREFERENCE AND LIMITATIONS

SITE	LOCATION	LIMITATION
1	0.450	1.000
2	0.100	1.000
3	0.450	1.000

*** ECONOMICS INPUTS ***

400-500 POUNO STEERS 0.7000 OOLLARS/POUND
500-600 POUNO STEERS 0.6700 OOLLARS/POUNO
600-700 POUNO STEERS 0.6400 OOLLARS/POUNO
700-800 POUND STEERS 0.6300 DOLLARS/POUNO
800-1100 POUNO STEERS 0.6500 OOLLARS/POUNO

OISCOUNT RATE = 12.0000 ANNUAL RATE

LIVESTOCK EXPENSES =$ 6.0000 /HEAD/MONTH

1970 YEAR SUMMARIES (WATER: IN PEAK:CFS SEDIMENT:TON VEGETATION:LB/AC PONDS:AC-FT)

INITIAL WATER STORAGE IN REPORTED SUBBASINS

CHANNEL ID	FIELDS	PONDS
1	6.473	0.000

INITIAL WATER STORAGE FOR FIELD REPORTS

REPORT NO.	STORAGE
1	8.822
2	2.134
3	8.822

SUBBASIN REPORT FOR CHANNEL 1

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
FIELDS:													
RAINFALL	0.515	1.355	1.979	0.723	0.171	0.256	0.145	0.077	0.461	1.664	1.364	0.847	9.559
INFILTR	0.515	1.277	1.991	0.723	0.171	0.256	0.145	0.077	0.461	1.664	0.891	1.283	9.456
RUNOFF	0.000	0.019	0.047	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.066
SOIL:													
RTN FLOW	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002
SOIL EVAP	0.522	0.138	0.967	1.291	0.322	0.059	0.126	0.071	0.303	0.468	0.470	0.101	4.837
PLANT EVAP	0.000	0.000	0.000	0.995	5.239	0.970	0.057	0.006	0.012	0.005	0.001	0.000	7.285
DEEP PERC	0.000	0.000	0.051	0.333	0.029	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.413
STORAGE	6.466	7.598	8.175	6.230	0.811	0.039	0.001	0.001	0.147	1.339	1.759	2.941	
CHANNEL:													
LOSSES	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
RUNOFF	0.000	0.019	0.048	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.068
PEAK	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BASIN WE	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.47	0.04	
LIVE VEG	0.00	0.00	0.00	382.09	1158.53	957.77	406.57	171.34	34.18	3.87	0.15	0.00	
DEAD VEG	1008.45	902.64	821.65	774.04	748.89	863.83	1190.97	1164.79	1090.51	920.70	831.42	767.96	
SEDIMENT:													
FIELD SED	0.00	0.02	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07
SILT-CLAY	0.00	0.09	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.14
BEDLOAD	0.00	0.01	0.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.39

FIELD REPORT NUMBER 1

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
FIELDS:													
RAINFALL	0.515	1.355	1.979	0.723	0.171	0.256	0.145	0.077	0.461	1.664	1.364	0.847	9.559
INFILTR	0.515	1.276	2.014	0.723	0.171	0.256	0.145	0.077	0.461	1.664	0.891	1.287	9.481
RUNOFF	0.000	0.017	0.027	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.044
SOIL:													
RTN FLOW	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002
SOIL EVAP	0.518	0.137	0.965	1.291	0.332	0.000	0.124	0.070	0.290	0.468	0.470	0.100	4.767
PLANT EVAP	0.000	0.000	0.000	1.060	6.840	1.434	0.076	0.006	0.011	0.005	0.001	0.000	9.434
DEEP PERC	0.000	0.000	0.096	0.498	0.044	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.638
FLD SN WAT	0.000	0.061	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.473	0.033	
STORAGE	8.818	9.938	10.396	8.278	1.233	0.056	0.001	0.002	0.161	1.353	1.772	2.959	
LIVE VEG	0.000	0.000	0.000	412.323	1430.214	1187.860	485.458	193.981	38.351	4.339	0.173	0.003	
DEAD VEG	945.610	836.513	757.338	712.776	692.146	848.672	1279.739	1243.476	1138.341	931.945	829.831	761.381	
SEDIMENT:													
FIELD SED	0.00	0.01	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03

FIELD REPORT NUMBER 2

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
FIELDS:													
RAINFALL	0.515	1.355	1.979	0.723	0.171	0.256	0.145	0.077	0.461	1.664	1.364	0.847	9.559
INFILTR	0.515	1.279	1.948	0.723	0.171	0.256	0.145	0.077	0.461	1.664	0.891	1.277	9.409
RUNOFF	0.000	0.022	0.085	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.107
SOIL:													
RTN FLOW	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
SOIL EVAP	0.526	0.139	0.970	1.290	0.304	0.167	0.129	0.073	0.326	0.467	0.469	0.102	4.960
PLANT EVAP	0.000	0.000	0.000	0.875	2.278	0.120	0.024	0.004	0.013	0.005	0.001	0.000	3.322
DEEP PERC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
FLD SN WAT	0.000	0.053	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.473	0.041	
STORAGE	2.123	3.264	4.046	2.450	0.039	0.008	0.000	0.000	0.121	1.314	1.735	2.910	
LIVE VEG	0.000	0.000	0.000	326.327	658.051	535.452	261.557	129.683	26.555	3.045	0.122	0.002	
DEAD VEG	1124.756	1025.106	940.822	887.512	853.885	892.611	1029.188	1021.378	1003.569	900.770	835.076	780.823	
SEDIMENT:													
FIELD SED	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02

FIELD REPORT NUMBER 3

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
FIELDS:													
RAINFALL	0.515	1.355	1.979	0.723	0.171	0.256	0.145	0.077	0.461	1.664	1.364	0.847	9.559
INFILTR	0.515	1.275	2.014	0.723	0.171	0.256	0.145	0.077	0.461	1.664	0.891	1.288	9.482
RUNOFF	0.000	0.017	0.027	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.044
SOIL:													
RTN FLOW	0.000	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004
SOIL EVAP	0.522	0.138	0.967	1.291	0.332	0.000	0.125	0.070	0.290	0.469	0.472	0.101	4.777
PLANT EVAP	0.000	0.000	0.000	1.061	6.842	1.424	0.075	0.006	0.011	0.005	0.001	0.000	9.424
DEEP PERC	0.000	0.000	0.050	0.539	0.047	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.636
FLD SN WAT	0.000	0.061	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.473	0.033	
STORAGE	8.815	9.952	10.433	8.273	1.223	0.056	0.001	0.002	0.161	1.352	1.770	2.957	
LIVE VEG	0.000	0.000	0.000	412.195	1428.073	1183.858	484.379	193.718	38.234	4.292	0.170	0.003	
DEAD VEG	945.325	836.123	756.870	712.385	691.919	847.561	1276.554	1240.678	1136.317	930.760	828.831	760.380	
SEDIMENT:													
FIELD SED	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02

BASIN LIVESTOCK REPORT FOR 1970

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
STEER (KG)	0.00	0.00	0.00	0.00	262.80	267.09	0.00	0.00	0.00	0.00	0.00	0.00	17.089
GRAZE DAYS	0	0	0	0	21	9	0	0	0	0	0	0	

*********** ECONOMICS REPORT FOR 1970***

STEER PURCHASE COST	ANNUAL VARIABLE COST	TOTAL ANNUAL COSTS	POUNDS OF BEEF SOLD	GROSS REVENUE	NET REVENUE	NET PRESENT VALUE
738.54	6.00	744.54	1177.65	789.02	44.48	44.05

******* NET PRESENT VALUE 44.05

Figure 12.6
The monthly/annual report generated by the basin-scale version of SPUR for Example No. 1. The simulation is for a watershed with a single channel, three fields, seven plant species, one wildlife species, and two grazing steers.

```
....:....1....:....2....:....3....:....4....:....5....:....6....:....7....:....8
 SPUR BASIN SCALE EXAMPLE 2
   1     0     0     0     1 1962     1     1      32.00
 000000659 000000421 000000879 000000127
 0.321 0.377 0.295 0.219 0.182 0.286 0.559 0.387 0.423 0.436 0.302 0.516
 0.076 0.053 0.079 0.035 0.024 0.045 0.287 0.259 0.135 0.066 0.052 0.071
 0.961 0.830 0.998 0.998 0.798 0.939 0.860 0.818 0.734 0.998 0.998 0.998
 0.178 0.215 0.183 0.129 0.147 0.166 0.288 0.315 0.383 0.257 0.208 0.174
    84.0     19.5     0.085      -.04
    75.0
    53.0     19.0     0.110      -.05
   525.0    210.0
   380.0
     8.1      5.4
  7.00  7.00  8.00  8.00  8.00  8.00  8.00  7.00  7.00  8.00  8.00  7.00
....:....1....:....2....:....3....:....4....:....5....:....6....:....7....:....8
```

Figure 12.7
The parameter file used to generate the weather sequence for Example No. 2 for the basin-scale version of SPUR. (The first and last lines are rulers to aid in locating data by column and are not part of the data file.)

```
                           Max.       Min.      Solar       Wind
  Day           Precip.    Temp.      Temp.      Rad.       Run
                 (in)      (°F)       (°F)    (langleys)    (m/h)
....:....1....:....2....:....3....:....4....:....5....:....6....:....7....:....8
     1          0.10971  52.25992  40.31051 170.66106 288.80563
     2          0.12233  54.24712  33.97086 188.50267 331.91403
     3          0.00000  69.27405  28.54874 357.35760 201.19775
     4          0.00000  68.08383  35.17991 298.70081 151.91389
     5          0.00000  64.72909  31.19975 359.89050 555.53918
     6          0.00000  60.33738  29.07791 361.27463 184.85323
     7          0.00000  60.00753  26.80350 362.73654 236.20108
     8          0.00000  54.09812  22.83222 232.17000  64.81472
     9          0.00000  53.74200  32.10583 365.89154 189.33849
    10          0.44191  58.10641  36.69470 241.57431 172.61816
    11          0.00000  70.56815  37.75680 343.32089 143.29649
    12          0.00000  68.20690  32.04528 333.59866 159.32462
    13          0.00000  66.19173  37.84615 251.24304 690.72473
    14          0.00000  58.98690  39.82817 183.36784 116.67968
    15          0.00000  63.62004  37.41726 273.65067 274.58206
....:....1....:....2....:....3....:....4....:....5....:....6....:....7....:....8
```

Figure 12.8
The first 15 records of the weather file generated for the basin-scale version of SPUR for Example No. 2. (The first and last lines are rulers to aid in locating data by column and are not part of the data file.)

```
....:....1....:....2....:....3....:....4....:....5....:....6....:....7....:....8
 SPUR BASIN SCALE TEST EXAMPLE 2
 1962    1    1    1    0.1688    02 0 0 0 0 0 1
 (11X,5F10.5)
  .7700000     0.200  .2300000     0.200     03.750
    1    0    0    3    1      .1140     3.0000     4.0000     2.0000
    8      .0200      .0300      .0400     0.5700      .0350    15.0000
   .094     .188     .38      .75      1.50     3.00     6.00     12.0
   .0570    .137     .241     .155     .157     .113     .053     .052
    0    0    0.0000    0.0000    0.0000    0.0000
    1    0    8    1    3.2000    86.0000   100.0000
     .1000      .0500    1.0000    1.3000    22.5000    0.0000    0.0000      .122
    0.0000    0.8000    0.5000
     .4400      .4400      .4400      .4000      .4000      .4000      .4000      .40
     .12        .12        .12        .12        .12        .12        .12        .12
     .045       .045       .045       .056       .056       .056       .056       .056
     .50        .45        .30        .30        .30        .30        .00        .30
    6.00       .5000      3.50       5.00       5.00       2.50       2.50       2.00
    2    1    8    2     2.800    86.0000   100.0000
     .1000      .1300    1.0000    1.3000    22.5000    0.0000    0.0000      .122
    0.0000    0.8000    0.5000
     .4400      .4400      .4400      .4000      .4000      .4000      .4000      .40
     .12        .12        .12        .12        .12        .12        .12        .12
     .045       .045       .045       .056       .056       .056       .056       .056
     .50        .45        .30        .30        .30        .30        .00        .30
    6.00       .50        3.50       5.00       5.00       2.50       2.50       2.00
    3    1    8    3    3.100    86.0000   100.0000
     .1000      .0500    1.0000    1.3000    22.5000    0.0000    0.0000      .122
    0.0000    0.8000    0.5000
     .4400      .4400      .4400      .4000      .4000      .4000      .4000      .40
     .12        .12        .12        .12        .12        .12        .12        .12
     .045       .045       .045       .056       .056       .056       .056       .056
     .50        .45        .30        .30        .30        .30        .00        .30
    6.00       .50        3.50       5.00       5.00       2.50       2.50       2.00
    2    1    0    2    1      .7580     9.0000    10.0000     2.0000
    8      .0151      .0260      .0350     0.7400      .0092    15.0000
   .082     .158     .32      .56      1.16     2.25     4.10      9.60
   .0188    .097     .195     .202     .198     .150     .080      .050
    0    0    0.0000    0.0000    0.0000    0.0000
    4    1    8    4   49.200    86.0000   100.0000
     .1000      .1300    1.0000    1.3000    22.5000    0.0000    0.0000      .122
    0.0000    0.8000    0.5000
     .4400      .4400      .4400      .4000      .4000      .4000      .4000      .40
     .12        .12        .12        .12        .12        .12        .12        .12
     .045       .045       .045       .056       .056       .056       .056       .056
     .50        .45        .30        .30        .30        .30        .00        .30
    6.00       .50        3.50       5.00       5.00       2.50       2.50       2.00
    5    1    8    5   49.700    86.0000   100.0000
     .1000      .0500    1.0000    1.3000    22.5000    0.0000    0.0000      .122
    0.0000    0.8000    0.5000
     .4400      .4400      .4400      .4000      .4000      .4000      .4000      .40
     .12        .12        .12        .12        .12        .12        .12        .12
     .045       .045       .045       .056       .056       .056       .056       .056
     .50        .45        .30        .30        .30        .30        .00        .30
    6.00       .50        3.50       5.00       5.00       2.50       2.50       2.00
     32.00   1980.00   1980.00
     1.000     5.000     3.000     0.200   800.000     5.000     0.500     0.900
     0.000    -2.000     0.020     0.300
....:....1....:....2....:....3....:....4....:....5....:....6....:....7....:....8
```

```
....:....1....:....2....:....3....:....4....:....5....:....6....:....7....:....8
      0.000
      1.000      5.000      3.000      0.200    800.000      5.000      0.500      0.900
      0.000     -2.000      0.020      0.300
      0.000
      1.000      5.000      3.000      0.200    800.000      5.000      0.500      0.900
      0.000     -2.000      0.020      0.300
      0.000
      1.000      5.000      3.000      0.200    800.000      5.000      0.500      0.900
      0.000     -2.000      0.020      0.300
      0.000
      1.000      5.000      3.000      0.200    800.000      5.000      0.500      0.900
      0.000     -2.000      0.020      0.300
      0.000
....:....1....:....2....:....3....:....4....:....5....:....6....:....7....:....8
```

Figure 12.9
The simulation control, hydrology and soils data file
for Example No. 2 using the basin-scale version of SPUR.
A watershed with two channels and five fields is simulated.
(The first and last lines are rulers to aid in locating
data by column and are not part of the data file.)

```
....:....1....:....2....:....3....:....4....:....5....:....6....:....7....:....8
    5   29    8
   WARM SEASON GRASSES
   COOL SEASON GRASSES
   WARM SEASON FORBS
   COOL SEASON FORBS
   SHRUBS
  75.00000  25.00000  20.00000  12.00000  15.00000
   0.40000   2.00000   0.15000   1.30000   1.30000
  45.00000  37.00000  45.00000  35.00000  40.00000
  27.00000  20.00000  27.00000  20.00000  21.00000
   5.00000   3.00000   5.00000   3.00000   3.00000
  25.00000  10.00000  15.00000   7.00000   8.50000
   9.96000   6.29000   7.04000   4.75000   6.40000
   0.70000   0.70000   0.70000   0.70000   0.70000
  10.00000  10.00000   4.00000   4.00000   5.00000
  -0.00010  -0.00020  -0.00040  -0.00050  -0.00002
  -0.25000  -0.40000  -0.60000  -0.65000  -0.00025
   0.05000   0.05000   0.06000   0.06000   0.00070
  -0.00900  -0.01000  -0.01000  -0.01000  -0.00090
  -0.00500  -0.00600  -0.00600  -0.00600   0.00000
   0.00400   0.00400   0.00400   0.00500   0.00050
   0.01500   0.02000   0.03000   0.03000   0.03000
   0.01000   0.02000   0.05000   0.05000   0.04000
   0.00500   0.00500   0.00500   0.00500   0.00500
   0.00500   0.01000   0.00500   0.00500   0.01000
  22.00000  72.00000  30.00000  15.00000  19.00000
   0.06000   0.06000   0.05000   0.05000   0.05000
   0.00000   0.00000   0.00000   0.00000   0.00000
   0.01000   0.01000   0.01000   0.01000   0.01000
   0.00250   0.00250   0.00100   0.00050   0.00150
   0.00500   0.00400   0.00200   0.00100   0.00050
   0.00800   0.00900   0.01000   0.01100   0.01000
....:....1....:....2....:....3....:....4....:....5....:....6....:....7....:....8
```

```
....:....1....:....2....:....3....:....4....:....5....:....6....:....7....:....8
-130.00000-115.00000-120.00000-110.00000-130.00000
   0.00300   0.00300   0.00200   0.00200   0.00100
   0.42000   0.42000   0.21000   0.21000   0.30000
   3.00000   3.00000   3.00000   3.00000   3.00000
  -2.00000  -6.00000  -1.00000  -3.00000  -4.00000
  12.50000   8.50000  13.00000   9.00000   8.50000
 -12.00000 -10.00000 -12.00000  -8.00000  -8.00000
  -5.00000  -3.00000  -5.00000  -3.00000  -1.00000
 180.00000 150.00000 200.00000 150.00000 160.00000
 190.00000 165.00000 200.00000 150.00000 200.00000
 220.00000 195.00000 220.00000 180.00000 220.00000
   0.01000 610.00000 147.000001800.00000
   0.00000   0.00000   0.00000   0.00000   0.00000
 256.39999  62.70000  35.00000  32.40000  45.00000
   0.00000   0.00000   0.00000   0.00000   0.00000
  54.00000  11.00000   3.00000   6.00000  30.00000
   0.01000 610.00000 147.000001800.00000
   0.00000   0.00000   0.00000   0.00000   0.00000
 256.39999  62.70000  35.00000  32.40000  45.00000
   0.00000   0.00000   0.00000   0.00000   0.00000
  54.00000  11.00000   3.00000   6.00000  30.00000
   0.01000 610.00000 147.000001800.00000
   0.00000   0.00000   0.00000   0.00000   0.00000
 256.39999  62.70000  35.00000  32.40000  45.00000
   0.00000   0.00000   0.00000   0.00000   0.00000
  54.00000  11.00000   3.00000   6.00000  30.00000
   0.01000 610.00000 147.000001800.00000
   0.00000   0.00000   0.00000   0.00000   0.00000
 256.39999  62.70000  35.00000  32.40000  45.00000
   0.00000   0.00000   0.00000   0.00000   0.00000
  54.00000  11.00000   3.00000   6.00000  30.00000
   0.01000 610.00000 147.000001800.00000
   0.00000   0.00000   0.00000   0.00000   0.00000
 256.39999  62.70000  35.00000  32.40000  45.00000
   0.00000   0.00000   0.00000   0.00000   0.00000
  54.00000  11.00000   3.00000   6.00000  30.00000
   0.01000   0.09000   0.00250  -0.02800   4.00000   2.23000
....:....1....:....2....:....3....:....4....:....5....:....6....:....7....:....8
```

Figure 12.10
The plant-component data file used in Example No. 2 with the basin-scale version of SPUR. Five plant species on five fields are simulated. (The first and last lines are rulers to aid in locating data by column and are not part of the data file.)

FIRST YEAR: 1962 NO. YEARS: 1
NO. CHANNELS: 2 TOTAL BASIN AREA (SQUARE MILES): 0.1688
PRINT SWITCHES: 0 0 1

MEAN RUNOFF DURATION COEFFICIENTS: 0.7700 0.2000
MEAN RUNOFF VOLUME COEFFICIENTS : 0.2300 -0.2000
MEAN RUNOFF PEAK RATE COEFFICIENT: 3.7500

****

CHAN ID	POND ID	NO. OF FIELDS	CHANNEL LINKAGE IN 1	IN 2	OUT	REPORT NOS. CHAN	POND	CHANNEL DIMENSIONS LENGTH (MI)	WIDTH (FT)	OUTLET (FT)	TRANSMISSION LOSS COEFFS. AXW (AC/FT)	BXW	FXW (MI)	HYDRL. CONDUCTIVITY CHANNEL (IN/HR)	POND (IN/HR)
1	0	3	0	0	2	1	0	0.11	3.00	4.00	-0.00105	0.99672	0.11381	2.000	0.000

POND AREA (AC)	POND VOLUMES INIT. (AC-FT)	FULL (AC-FT)	CHANNEL SUBBASIN PARAMETERS MEAN DUR (HR)	MEAN VOL (AC-FT)	MEAN PEAK (IN/HR)	AREA (AC)	CHANNEL SLOPE	ROUGHNESS TOTAL (SEC/FT**(1/3))	WALL	MEDIAN DIAMETER (MM)	FRACTION SILT & CLAY	CAS (SEC/FT)
0.000	0.0000	0.0000	0.3289	0.4083	6.1394	9.100	0.0200	0.0300	0.0400	0.5700	0.0350	15.0000

PARTICLE CLASS	DIAMETER (MM)	FRACTION IN BED
1	0.0940	0.0570
2	0.1880	0.1370
3	0.3800	0.2410
4	0.7500	0.1550
5	1.5000	0.1570
6	3.0000	0.1130
7	6.0000	0.0530
8	12.0000	0.0520

FIELD ID	FIELD TYPE	FIELD REPORT NO.	# SOIL LAYERS	FIELD AREA (AC)	CURVE NUMBER	RETURN FLOW TIME (DAY)	MODIFIED USLE FACTORS FOR FIELD SOIL	COVER	CONTROL	SL
1	UPLAND	1	8	3.200	86.00	100.00	0.10	0.05	1.00	1.30

SOIL LAYER PARAMETERS

	1 LAYER	2 LAYER	3 LAYER	4 LAYER	5 LAYER	6 LAYER	7 LAYER	8 LAYER
SOIL POROSITY (IN/IN):	0.440	0.440	0.440	0.400	0.400	0.400	0.400	0.400
WATER AT .3 BAR (IN/IN):	0.120	0.120	0.120	0.120	0.120	0.120	0.120	0.120
WATER AT 15 BAR (IN/IN):	0.045	0.045	0.045	0.056	0.056	0.056	0.056	0.056
SATURATED COND. (IN/HR):	0.500	0.450	0.300	0.300	0.300	0.300	0.000	0.300
SOIL DEPTH, ACC. (IN):	6.000	6.500	10.000	15.000	20.000	22.500	25.000	27.000
FIELD CAPACITY (IN):	0.522	0.044	0.305	0.380	0.380	0.190	0.190	0.152
MAXIMUM STORAGE (IN):	2.442	0.204	1.425	1.780	1.780	0.890	0.890	0.712

FIELD ID	FIELD TYPE	FIELD REPORT NO.	# SOIL LAYERS	FIELD AREA (AC)	CURVE NUMBER	RETURN FLOW TIME (DAY)	MODIFIED USLE FACTORS FOR FIELD SOIL	COVER	CONTROL	SL
2	LATERAL	2	8	2.800	86.00	100.00	0.10	0.13	1.00	1.30

SOIL LAYER PARAMETERS

	1 LAYER	2 LAYER	3 LAYER	4 LAYER	5 LAYER	6 LAYER	7 LAYER	8 LAYER
SOIL POROSITY (IN/IN):	0.440	0.440	0.440	0.400	0.400	0.400	0.400	0.400
WATER AT .3 BAR (IN/IN):	0.120	0.120	0.120	0.120	0.120	0.120	0.120	0.120
WATER AT 15 BAR (IN/IN):	0.045	0.045	0.045	0.056	0.056	0.056	0.056	0.056
SATURATED COND. (IN/HR):	0.500	0.450	0.300	0.300	0.300	0.300	0.000	0.300
SOIL DEPTH, ACC. (IN):	6.000	6.500	10.000	15.000	20.000	22.500	25.000	27.000
FIELD CAPACITY (IN):	0.522	0.044	0.305	0.380	0.380	0.190	0.190	0.152
MAXIMUM STORAGE (IN):	2.442	0.204	1.425	1.780	1.780	0.890	0.890	0.712

FIELD ID	FIELD TYPE	FIELD REPORT NO.	# SOIL LAYERS	FIELD AREA (AC)	CURVE NUMBER	RETURN FLOW TIME (DAY)	MODIFIED USLE FACTORS FOR FIELD SOIL	COVER	CONTROL	SL
3	LATERAL	3	8	3.100	86.00	100.00	0.10	0.05	1.00	1.30

SOIL LAYER PARAMETERS

	1 LAYER	2 LAYER	3 LAYER	4 LAYER	5 LAYER	6 LAYER	7 LAYER	8 LAYER
SOIL POROSITY (IN/IN):	0.440	0.440	0.440	0.400	0.400	0.400	0.400	0.400
WATER AT .3 BAR (IN/IN):	0.120	0.120	0.120	0.120	0.120	0.120	0.120	0.120
WATER AT 15 BAR (IN/IN):	0.045	0.045	0.045	0.056	0.056	0.056	0.056	0.056
SATURATED COND. (IN/HR):	0.500	0.450	0.300	0.300	0.300	0.300	0.000	0.300
SOIL DEPTH, ACC. (IN):	6.000	6.500	10.000	15.000	20.000	22.500	25.000	27.000
FIELD CAPACITY (IN):	0.522	0.044	0.305	0.380	0.380	0.190	0.190	0.152
MAXIMUM STORAGE (IN):	2.442	0.204	1.425	1.780	1.780	0.890	0.890	0.712

****

CHAN ID	POND ID	NO. OF FIELDS	CHANNEL LINKAGE IN 1	IN 2	OUT	REPORT NOS. CHAN	POND	CHANNEL DIMENSIONS LENGTH (MI)	WIDTH (FT)	OUTLET (FT)	TRANSMISSION LOSS COEFFS. AXW (AC/FT)	BXW	FXW (MI)	HYDRL. CONDUCTIVITY CHANNEL (IN/HR)	POND (IN/HR)
2	0	2	1	0	0	1	0	0.76	9.00	10.00	-0.03401	0.98530	0.75241	2.000	0.000

POND AREA (AC)	POND VOLUMES INIT. (AC-FT)	FULL (AC-FT)	CHANNEL SUBBASIN PARAMETERS MEAN DUR (HR)	MEAN VOL (AC-FT)	MEAN PEAK (IN/HR)	AREA (AC)	CHANNEL SLOPE	ROUGHNESS TOTAL (SEC/FT**(1/3))	WALL	MEDIAN DIAMETER (MM)	FRACTION SILT & CLAY	CAS (SEC/FT)
0.000	0.0000	0.0000	0.5394	2.9548	2.2823	108.000	0.0151	0.0260	0.0350	0.7400	0.0092	15.0000

PARTICLE CLASS	DIAMETER (MM)	FRACTION IN BED
1	0.0820	0.0188
2	0.1580	0.0970
3	0.3200	0.1950
4	0.5600	0.2020
5	1.1600	0.1980
6	2.2500	0.1500
7	4.1000	0.0800
8	9.6000	0.0500

FIELD ID	FIELD TYPE	FIELD REPORT NO.	# SOIL LAYERS	FIELD AREA (AC)	CURVE NUMBER	RETURN FLOW TIME (DAY)	MODIFIED USLE FACTORS FOR FIELD SOIL	COVER	CONTROL	SL
4	LATERAL	4	8	49.200	86.00	100.00	0.10	0.13	1.00	1.30

SOIL LAYER PARAMETERS

	1 LAYER	2 LAYER	3 LAYER	4 LAYER	5 LAYER	6 LAYER	7 LAYER	8 LAYER
SOIL POROSITY (IN/IN):	0.440	0.440	0.440	0.400	0.400	0.400	0.400	0.400
WATER AT .3 BAR (IN/IN):	0.120	0.120	0.120	0.120	0.120	0.120	0.120	0.120
WATER AT 15 BAR (IN/IN):	0.045	0.045	0.045	0.056	0.056	0.056	0.056	0.056
SATURATED COND. (IN/HR):	0.500	0.450	0.300	0.300	0.300	0.300	0.000	0.300
SOIL DEPTH, ACC. (IN):	6.000	6.500	10.000	15.000	20.000	22.500	25.000	27.000
FIELD CAPACITY (IN):	0.522	0.044	0.305	0.380	0.380	0.190	0.190	0.152
MAXIMUM STORAGE (IN):	2.442	0.204	1.425	1.780	1.780	0.890	0.890	0.712

FIELD ID	FIELD TYPE	FIELD REPORT NO.	# SOIL LAYERS	FIELD AREA (AC)	CURVE NUMBER	RETURN FLOW TIME (DAY)	MODIFIED USLE FACTORS FOR FIELD SOIL	COVER	CONTROL	SL
5	LATERAL	5	8	49.700	86.00	100.00	0.10	0.05	1.00	1.30

SOIL LAYER PARAMETERS

	1 LAYER	2 LAYER	3 LAYER	4 LAYER	5 LAYER	6 LAYER	7 LAYER	8 LAYER
SOIL POROSITY (IN/IN):	0.440	0.440	0.440	0.400	0.400	0.400	0.400	0.400
WATER AT .3 BAR (IN/IN):	0.120	0.120	0.120	0.120	0.120	0.120	0.120	0.120
WATER AT 15 BAR (IN/IN):	0.045	0.045	0.045	0.056	0.056	0.056	0.056	0.056
SATURATED COND. (IN/HR):	0.500	0.450	0.300	0.300	0.300	0.300	0.000	0.300
SOIL DEPTH, ACC. (IN):	6.000	6.500	10.000	15.000	20.000	22.500	25.000	27.000
FIELD CAPACITY (IN):	0.522	0.044	0.305	0.380	0.380	0.190	0.190	0.152
MAXIMUM STORAGE (IN):	2.442	0.204	1.425	1.780	1.780	0.890	0.890	0.712

++ PLANT COMPONENT INPUTS ++

NUMBER OF PLANT SPECIES = 5
NUMBER OF PARAMETERS PER PLANT SPECIES = 29
NUMBER OF CRITICAL VALUES PER PLANT SPECIES = 8

SPECIES 1 IS WARM SEASON GRASSES
SPECIES 2 IS COOL SEASON GRASSES
SPECIES 3 IS WARM SEASON FORBS
SPECIES 4 IS COOL SEASON FORBS
SPECIES 5 IS SHRUBS

SPECIES	1	2	3	4	5
PARAMETER 1	75.00000	25.00000	20.00000	12.00000	15.00000
PARAMETER 2	0.40000	2.00000	0.15000	1.30000	1.30000
PARAMETER 3	45.00000	37.00000	45.00000	35.00000	40.00000
PARAMETER 4	27.00000	20.00000	27.00000	20.00000	21.00000
PARAMETER 5	5.00000	3.00000	5.00000	3.00000	3.00000
PARAMETER 6	25.00000	10.00000	15.00000	7.00000	8.50000
PARAMETER 7	9.96000	6.29000	7.04000	4.75000	6.40000
PARAMETER 8	0.70000	0.70000	0.70000	0.70000	0.70000
PARAMETER 9	10.00000	10.00000	4.00000	4.00000	5.00000
PARAMETER 10	-0.00010	-0.00020	-0.00040	-0.00050	-0.00002
PARAMETER 11	-0.25000	-0.40000	-0.60000	-0.65000	-0.00025
PARAMETER 12	0.05000	0.05000	0.06000	0.06000	0.00070
PARAMETER 13	-0.00900	-0.01000	-0.01000	-0.01000	-0.00090
PARAMETER 14	-0.00500	-0.00600	-0.00600	-0.00600	0.00000
PARAMETER 15	0.00400	0.00400	0.00400	0.00500	0.00050
PARAMETER 16	0.01500	0.02000	0.03000	0.03000	0.03000
PARAMETER 17	0.01000	0.02000	0.05000	0.05000	0.04000
PARAMETER 18	0.00500	0.00500	0.00500	0.00500	0.00500
PARAMETER 19	0.00500	0.01000	0.00500	0.00500	0.01000
PARAMETER 20	22.00000	72.00000	30.00000	15.00000	19.00000
PARAMETER 21	0.06000	0.06000	0.05000	0.05000	0.05000
PARAMETER 22	0.00000	0.00000	0.00000	0.00000	0.00000
PARAMETER 23	0.01000	0.01000	0.01000	0.01000	0.01000
PARAMETER 24	0.00250	0.00250	0.00100	0.00050	0.00150
PARAMETER 25	0.00500	0.00400	0.00200	0.00100	0.00050
PARAMETER 26	0.00800	0.00900	0.01000	0.01100	0.01000
PARAMETER 27	-130.00000	-115.00000	-120.00000	-110.00000	-130.00000
PARAMETER 28	0.00300	0.00300	0.00200	0.00200	0.00100
PARAMETER 29	0.42000	0.42000	0.21000	0.21000	0.30000
CRITICAL VALUE 1	3.00000	3.00000	3.00000	3.00000	3.00000
CRITICAL VALUE 2	-2.00000	-6.00000	-1.00000	-3.00000	-4.00000
CRITICAL VALUE 3	12.50000	8.50000	13.00000	9.00000	8.50000
CRITICAL VALUE 4	-12.00000	-10.00000	-12.00000	-8.00000	-8.00000
CRITICAL VALUE 5	-5.00000	-3.00000	-5.00000	-3.00000	-1.00000
CRITICAL VALUE 6	180.00000	150.00000	200.00000	150.00000	160.00000
CRITICAL VALUE 7	190.00000	165.00000	200.00000	150.00000	200.00000
CRITICAL VALUE 8	220.00000	195.00000	220.00000	180.00000	220.00000

FIELD NUMBER 1 INITIAL CONDITIONS:

PLANT SPECIES	STANDING GREEN (C)	STANDING GREEN (N)	LIVE ROOTS (C)	LIVE ROOTS (N)	PROPAGULES (C)	PROPAGULES (N)	STANDING DEAD (C)	STANDING DEAD(N)
1	0.000	0.000	256.400	2.564	0.000	0.000	54.000	0.270
2	0.000	0.000	62.700	0.627	0.000	0.000	11.000	0.055
3	0.000	0.000	35.000	0.350	0.000	0.000	3.000	0.015
4	0.000	0.000	32.400	0.324	0.000	0.000	6.000	0.030
5	0.000	0.000	45.000	0.450	0.000	0.000	30.000	0.150

NONSPECIES SPECIFIC INITIAL VALUES:

DEAD ROOTS (C)	DEAD ROOTS (N)	LITTER (C)	LITTER (N)	ORGANIC MATTER (C)	ORGANIC MATTER (N)	SOIL INORGANIC NITROGEN
610.000	3.660	147.000	1.470	1800.000	72.000	0.010

FIELD NUMBER 2 INITIAL CONDITIONS:

PLANT SPECIES	STANDING GREEN (C)	STANDING GREEN (N)	LIVE ROOTS (C)	LIVE ROOTS (N)	PROPAGULES (C)	PROPAGULES (N)	STANDING DEAD (C)	STANDING DEAD(N)
1	0.000	0.000	256.400	2.564	0.000	0.000	54.000	0.270
2	0.000	0.000	62.700	0.627	0.000	0.000	11.000	0.055
3	0.000	0.000	35.000	0.350	0.000	0.000	3.000	0.015
4	0.000	0.000	32.400	0.324	0.000	0.000	6.000	0.030
5	0.000	0.000	45.000	0.450	0.000	0.000	30.000	0.150

NONSPECIES SPECIFIC INITIAL VALUES:

DEAD ROOTS (C)	DEAD ROOTS (N)	LITTER (C)	LITTER (N)	ORGANIC MATTER (C)	ORGANIC MATTER (N)	SOIL INORGANIC NITROGEN
610.000	3.660	147.000	1.470	1800.000	72.000	0.010

FIELD NUMBER 3 INITIAL CONDITIONS:

PLANT SPECIES	STANDING GREEN (C)	STANDING GREEN (N)	LIVE ROOTS (C)	LIVE ROOTS (N)	PROPAGULES (C)	PROPAGULES (N)	STANDING DEAD (C)	STANDING DEAD(N)
1	0.000	0.000	256.400	2.564	0.000	0.000	54.000	0.270
2	0.000	0.000	62.700	0.627	0.000	0.000	11.000	0.055
3	0.000	0.000	35.000	0.350	0.000	0.000	3.000	0.015
4	0.000	0.000	32.400	0.324	0.000	0.000	6.000	0.030
5	0.000	0.000	45.000	0.450	0.000	0.000	30.000	0.150

NONSPECIES SPECIFIC INITIAL VALUES:

DEAD ROOTS (C)	DEAD ROOTS (N)	LITTER (C)	LITTER (N)	ORGANIC MATTER (C)	ORGANIC MATTER (N)	SOIL INORGANIC NITROGEN
610.000	3.660	147.000	1.470	1800.000	72.000	0.010

FIELD NUMBER 4 INITIAL CONDITIONS:

PLANT SPECIES	STANDING GREEN (C)	STANDING GREEN (N)	LIVE ROOTS (C)	LIVE ROOTS (N)	PROPAGULES (C)	PROPAGULES (N)	STANDING DEAD (C)	STANDING DEAD(N)
1	0.000	0.000	256.400	2.564	0.000	0.000	54.000	0.270
2	0.000	0.000	62.700	0.627	0.000	0.000	11.000	0.055
3	0.000	0.000	35.000	0.350	0.000	0.000	3.000	0.015
4	0.000	0.000	32.400	0.324	0.000	0.000	6.000	0.030
5	0.000	0.000	45.000	0.450	0.000	0.000	30.000	0.150

NONSPECIES SPECIFIC INITIAL VALUES:

DEAD ROOTS (C)	DEAD ROOTS (N)	LITTER (C)	LITTER (N)	ORGANIC MATTER (C)	ORGANIC MATTER (N)	SOIL INORGANIC NITROGEN
610.000	3.660	147.000	1.470	1800.000	72.000	0.010

FIELD NUMBER 5 INITIAL CONDITIONS:

PLANT SPECIES	STANDING GREEN (C)	STANDING GREEN (N)	LIVE ROOTS (C)	LIVE ROOTS (N)	PROPAGULES (C)	PROPAGULES (N)	STANDING DEAD (C)	STANDING DEAD(N)
1	0.000	0.000	256.400	2.564	0.000	0.000	54.000	0.270
2	0.000	0.000	62.700	0.627	0.000	0.000	11.000	0.055
3	0.000	0.000	35.000	0.350	0.000	0.000	3.000	0.015
4	0.000	0.000	32.400	0.324	0.000	0.000	6.000	0.030
5	0.000	0.000	45.000	0.450	0.000	0.000	30.000	0.150

NONSPECIES SPECIFIC INITIAL VALUES:

DEAD ROOTS (C)	DEAD ROOTS (N)	LITTER (C)	LITTER (N)	ORGANIC MATTER (C)	ORGANIC MATTER (N)	SOIL INORGANIC NITROGEN
610.000	3.660	147.000	1.470	1800.000	72.000	0.010

NONSITE-NONSPECIES SPECIFIC PARAMETERS:

0.010	0.090	0.002	-0.028	4.000	2.230

1962 YEAR SUMMARIES (WATER:IN PEAK:CFS SEDIMENT:TON VEGETATION:LB/AC PONOS:AC-FT)

INITIAL WATER STORAGE IN REPORTEO SUBBASINS

CHANNEL IO	FIELDS	PONOS
1	1.608	0.000
2	1.608	0.000

INITIAL WATER STORAGE FOR FIELD REPORTS

REPORT NO.	STORAGE
1	1.608
2	1.608
3	1.608
4	1.608
5	1.608

SUBBASIN REPORT FOR CHANNEL 1

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	OEC	YEAR
FIELOS:													
RAINFALL	0.717	0.741	1.454	0.484	0.000	0.552	2.833	1.646	2.477	0.735	0.438	0.421	12.498
INFILTR	0.698	0.723	1.392	0.484	0.000	0.552	2.786	1.580	1.710	0.733	0.433	0.421	11.512
RUNOFF	0.018	0.018	0.062	0.000	0.000	0.000	0.048	0.066	0.767	0.002	0.006	0.000	0.985
SOIL:													
RTN FLOW	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
SOIL EVAP	1.048	0.551	0.388	0.745	0.000	0.348	1.772	1.040	1.150	0.747	0.416	0.415	8.621
PLANT EVAP	0.022	0.613	1.125	0.413	0.000	0.162	1.040	0.185	0.461	0.285	0.053	0.008	4.367
OEEP PERC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
STORAGE	1.236	0.794	0.674	0.001	0.000	0.042	0.015	0.370	0.469	0.170	0.134	0.132	
CHANNEL:													
LOSSES	0.001	0.001	0.004	0.000	0.000	0.000	0.003	0.003	0.003	0.002	0.001	0.000	0.019
RUNOFF	0.017	0.017	0.058	0.000	0.000	0.000	0.045	0.063	0.764	0.000	0.004	0.000	0.967
PEAK	1.8	1.7	5.2	0.0	0.0	0.0	4.1	5.6	79.9	0.0	0.4	0.0	79.9
BASIN WE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
LIVE VEG	38.34	217.05	289.25	352.46	320.89	269.02	258.44	85.09	120.79	43.53	10.56	2.15	
DEAD VEG	695.97	564.08	438.54	385.20	356.07	336.40	349.32	457.56	552.89	611.07	554.25	488.39	
SEOIMENT:													
FIELD SEO	0.06	0.06	0.21	0.00	0.00	0.00	0.16	0.23	3.81	0.00	0.02	0.00	4.56
SILT-CLAY	0.07	0.07	0.33	0.00	0.00	0.00	0.24	0.37	7.18	0.00	0.01	0.00	8.27
BEOLOAD	0.13	0.13	0.54	0.00	0.00	0.00	0.40	0.60	8.49	0.00	0.02	0.00	10.31

SUBBASIN REPORT FOR CHANNEL 2

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
FIELDS:													
RAINFALL	0.717	0.741	1.454	0.484	0.000	0.552	2.833	1.646	2.477	0.735	0.438	0.421	12.498
INFILTR	0.698	0.723	1.392	0.484	0.000	0.552	2.786	1.580	1.710	0.733	0.433	0.421	11.512
RUNOFF	0.018	0.018	0.062	0.000	0.000	0.000	0.048	0.066	0.767	0.002	0.006	0.000	0.985
SOIL:													
RTN FLOW	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
SOIL EVAP	1.048	0.551	0.388	0.745	0.000	0.348	1.772	1.040	1.150	0.747	0.416	0.415	8.621
PLANT EVAP	0.022	0.613	1.125	0.413	0.000	0.162	1.040	0.185	0.461	0.285	0.053	0.008	4.367
DEEP PERC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
STORAGE	1.236	0.794	0.674	0.001	0.000	0.042	0.015	0.370	0.469	0.170	0.134	0.132	
CHANNEL:													
LOSSES	0.004	0.004	0.009	0.000	0.000	0.000	0.008	0.008	0.010	0.002	0.004	0.000	0.050
RUNOFF	0.014	0.014	0.052	0.000	0.000	0.000	0.039	0.057	0.756	0.000	0.002	0.000	0.936
PEAK	10.8	10.6	35.5	0.0	0.0	0.0	27.7	38.2	572.7	0.0	1.3	0.0	572.7
BASIN WE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
LIVE VEG	38.34	217.05	289.25	352.46	320.89	269.02	258.44	85.09	120.79	43.53	10.56	2.15	
DEAD VEG	695.97	564.08	438.54	385.20	356.07	336.40	349.32	457.56	552.89	611.07	554.25	488.39	
SEDIMENT:													
FIELD SED	0.83	0.83	3.08	0.00	0.00	0.00	2.33	3.33	54.83	0.06	0.22	0.00	65.51
SILT-CLAY	0.28	0.28	1.48	0.00	0.00	0.00	1.04	1.65	40.84	0.00	0.01	0.00	45.58
BEDLOAD	1.16	1.14	5.33	0.00	0.00	0.00	3.85	5.91	98.28	0.00	0.06	0.00	115.73

FIELD REPORT NUMBER 1

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
FIELDS:													
RAINFALL	0.717	0.741	1.454	0.484	0.000	0.552	2.833	1.646	2.477	0.735	0.438	0.421	12.498
INFILTR	0.698	0.723	1.392	0.484	0.000	0.552	2.786	1.580	1.710	0.733	0.433	0.421	11.512
RUNOFF	0.018	0.018	0.062	0.000	0.000	0.000	0.048	0.066	0.767	0.002	0.006	0.000	0.985
SOIL:													
RTN FLOW	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
SOIL EVAP	1.048	0.551	0.388	0.745	0.000	0.348	1.772	1.040	1.150	0.747	0.416	0.415	8.621
PLANT EVAP	0.022	0.613	1.125	0.413	0.000	0.162	1.040	0.185	0.461	0.285	0.053	0.008	4.367
DEEP PERC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
FLD SN WAT	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
STORAGE	1.236	0.794	0.674	0.001	0.000	0.042	0.015	0.370	0.469	0.170	0.134	0.132	
LIVE VEG	38.344	217.048	289.250	352.458	320.895	269.021	258.435	85.094	120.794	43.532	10.556	2.147	
DEAD VEG	695.970	564.084	438.536	385.202	356.068	336.398	349.323	457.563	552.885	611.069	554.252	488.393	
SEDIMENT:													
FIELD SED	0.01	0.01	0.05	0.00	0.00	0.00	0.04	0.05	0.90	0.00	0.00	0.00	1.07

FIELD REPORT NUMBER 2

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
FIELDS:													
RAINFALL	0.717	0.741	1.454	0.484	0.000	0.552	2.833	1.646	2.477	0.735	0.438	0.421	12.498
INFILTR	0.698	0.723	1.392	0.484	0.000	0.552	2.786	1.580	1.710	0.733	0.433	0.421	11.512
RUNOFF	0.018	0.018	0.062	0.000	0.000	0.000	0.048	0.066	0.767	0.002	0.006	0.000	0.985
SOIL:													
RTN FLOW	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
SOIL EVAP	1.048	0.551	0.388	0.745	0.000	0.348	1.772	1.040	1.150	0.747	0.416	0.415	8.621
PLANT EVAP	0.022	0.613	1.125	0.413	0.000	0.162	1.040	0.185	0.461	0.285	0.053	0.008	4.367
DEEP PERC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
FLD SN WAT	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
STORAGE	1.236	0.794	0.674	0.001	0.000	0.042	0.015	0.370	0.469	0.170	0.134	0.132	
LIVE VEG	38.344	217.048	289.250	352.458	320.895	269.021	258.435	85.094	120.794	43.532	10.556	2.147	
DEAD VEG	695.970	564.083	438.536	385.202	356.068	336.398	349.323	457.563	552.885	611.069	554.252	488.393	
SEDIMENT:													
FIELD SED	0.03	0.03	0.11	0.00	0.00	0.00	0.09	0.12	2.04	0.00	0.01	0.00	2.44

FIELD REPORT NUMBER 3

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
FIELDS:													
RAINFALL	0.717	0.741	1.454	0.484	0.000	0.552	2.833	1.646	2.477	0.735	0.438	0.421	12.498
INFILTR	0.698	0.723	1.392	0.484	0.000	0.552	2.786	1.580	1.710	0.733	0.433	0.421	11.512
RUNOFF	0.018	0.018	0.062	0.000	0.000	0.000	0.048	0.066	0.767	0.002	0.006	0.000	0.985
SOIL:													
RTN FLOW	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
SOIL EVAP	1.048	0.551	0.388	0.745	0.000	0.348	1.772	1.040	1.150	0.747	0.416	0.415	8.621
PLANT EVAP	0.022	0.613	1.125	0.413	0.000	0.162	1.040	0.185	0.461	0.285	0.053	0.008	4.367
DEEP PERC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
FLD SN WAT	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
STORAGE	1.236	0.794	0.674	0.001	0.000	0.042	0.015	0.370	0.469	0.170	0.134	0.132	
LIVE VEG	38.344	217.048	289.250	352.458	320.895	269.021	258.435	85.094	120.794	43.532	10.556	2.147	
DEAD VEG	695.970	564.084	438.536	385.202	356.068	336.398	349.323	457.563	552.885	611.069	554.252	488.393	
SEDIMENT:													
FIELD SED	0.01	0.01	0.05	0.00	0.00	0.00	0.04	0.05	0.87	0.00	0.00	0.00	1.04

FIELD REPORT NUMBER 4

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
FIELDS:													
RAINFALL	0.717	0.741	1.454	0.484	0.000	0.552	2.833	1.646	2.477	0.735	0.438	0.421	12.498
INFILTR	0.698	0.723	1.392	0.484	0.000	0.552	2.786	1.580	1.710	0.733	0.433	0.421	11.512
RUNOFF	0.018	0.018	0.062	0.000	0.000	0.000	0.048	0.066	0.767	0.002	0.006	0.000	0.985
SOIL:													
RTN FLOW	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
SOIL EVAP	1.048	0.551	0.388	0.745	0.000	0.348	1.772	1.041	1.150	0.747	0.416	0.415	8.621
PLANT EVAP	0.022	0.613	1.125	0.413	0.000	0.162	1.040	0.185	0.461	0.285	0.053	0.008	4.367
DEEP PERC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
FLD SN WAT	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
STORAGE	1.236	0.794	0.674	0.001	0.000	0.042	0.015	0.370	0.469	0.170	0.134	0.132	
LIVE VEG	38.344	217.048	289.250	352.458	320.895	269.021	258.435	85.094	120.794	43.532	10.556	2.147	
DEAD VEG	695.970	564.084	438.536	385.202	356.068	336.398	349.323	457.563	552.885	611.069	554.252	488.393	
SEDIMENT:													
FIELD SED	0.56	0.55	2.06	0.00	0.00	0.00	1.56	2.23	36.74	0.04	0.15	0.00	43.90

FIELD REPORT NUMBER 5

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
FIELDS:													
RAINFALL	0.717	0.741	1.454	0.484	0.000	0.552	2.833	1.646	2.477	0.735	0.438	0.421	12.498
INFILTR	0.698	0.723	1.392	0.484	0.000	0.552	2.786	1.580	1.710	0.733	0.433	0.421	11.512
RUNOFF	0.018	0.018	0.062	0.000	0.000	0.000	0.048	0.066	0.767	0.002	0.006	0.000	0.985
SOIL:													
RTN FLOW	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
SOIL EVAP	1.048	0.551	0.388	0.745	0.000	0.348	1.772	1.040	1.150	0.747	0.416	0.415	8.621
PLANT EVAP	0.022	0.613	1.125	0.413	0.000	0.162	1.040	0.185	0.461	0.285	0.053	0.008	4.367
DEEP PERC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
FLD SN WAT	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
STORAGE	1.236	0.794	0.674	0.001	0.000	0.042	0.015	0.370	0.469	0.170	0.134	0.132	
LIVE VEG	38.344	217.048	289.250	352.458	320.895	269.021	258.435	85.094	120.794	43.532	10.556	2.147	
DEAD VEG	695.970	564.084	438.536	385.202	356.068	336.398	349.323	457.563	552.885	611.069	554.252	488.393	
SEDIMENT:													
FIELD SED	0.22	0.22	0.80	0.00	0.00	0.00	0.61	0.87	14.28	0.02	0.06	0.00	17.06

Figure 12.11
The monthly/annual report generated by the basin-scale version of SPUR for Example No. 2. The simulation is for a watershed with two channels, five fields, and five plant species.

13. GLOSSARY OF TERMS

J.W. Skiles

INTRODUCTION

The authors of the SPUR Documentation and User Guide necessarily used some specialized terms. While these terms have not been redefined, they have connotations unique to the SPUR modeling effort. The user may review the terms and definitions that follow for a better understanding of how these terms are used in this volume.

GLOSSARY

abscission - a physiological process whereby plants shed a part such as a leaf, flower, seed, or fruit

algorithm - a series of specific steps for solving a problem, usually used in the context of a set of instructions a computer follows as it processes data

alphanumeric - a literal string consisting of both letters and numbers and possibly including other symbols such as punctuation marks

aspect - the general horizontal direction in which a slope faces, commonly expressed in degrees clockwise from north; a west-facing slope, for example, has an aspect of 270 degrees

asymptote - a line approached by a curve in the limit as the curve approaches infinity; the limit of the tangents to a curve as the point of contact approaches infinity

attribute - a characteristic of a site or phenomenon

autotroph - an organism capable of synthesizing complex organic substances from simple inorganic substrates

benchmark - a problem or mix of problems to be run on computers to evaluate their performances relative to one another

binary word - a group of bits which occupies one storage address and is treated by the computer as a unit

bit - abbreviation for binary digit; a variable that can take only the values zero or one in computer memory

BLOCK DATA - a segment of the program which defines in computer storage all of the values of variables passed between modules by COMMON statements; the values are assigned at compile time

bottom land - low land through which a river flows, rich in alluvial deposits; flood plain

bug - an error in a program or computing system

byte - a sequence of adjacent binary digits operated upon as a unit in a computer; current use equates one byte as one terminal key stroke or one character

C_3 plant - a plant employing the pentose phosphate pathway of carbon dioxide assimilation during photosynthesis; most green plants belong to this category; these species typically have maximum production during the cooler part of the growing season

C_4 plant - a plant employing the dicarboxylic acid pathway for carbon dioxide assimilation during photosynthesis and capable of utilizing lower carbon dioxide concentrations than C_3 plants; these species typically have maximum production during the warmer part of the growing season

caliche - a layer near the surface, somewhat cemented by secondary carbonates of calcium or magnesium precipitated from the soil solution; occurring as a soft thin soil horizon, as a hard thick bed just beneath the solum, or as a surface layer exposed by erosion

catenae - a series of soils of similar age and derived from parent material, found under similar climatic conditions but showing different properties due to variations in soil-forming factors

Crassulacean Acid Metabolism (CAM) plants - plants (especially succulents) employing a carbon dioxide fixation pathway which fixes large amounts of carbon dioxide in the dark and stores malate within their cells

code - the higher-level computer language used to program a digital computer; in this case, FORTRAN IV

compartment - in a typical box-and-arrow diagram, refers to the state of a variable or the level of currency therein (see state variable; currency)

compiler - a program for translating instructions written in a high-level language into machine instructions

component - refers to a section of code consisting of one or more subroutines containing the mathematics which describe a particular function or operation of the model, for example, hydrology component, plant component, animal component

constant - a word or number in computer memory identified by a label in the program and, in contrast to a variable, assigned a value that does not change during the execution of the program

consumer food requirments - minimum or threshold amount of energy required for a consumer to maintain or increase its energy or nutrient balance; dependent on food quality, ambient temperature, metabolic rate, body size, physiological state, and reproductive state

core - see magnetic core storage

cool-season plants - see C_3 plants

CPU - an acronym for Central Processing Unit, the part of the computer that controls the flow of data and performs the computations

CRT - an acronym for Cathode-Ray Tube, on which an image is displayed by directing a beam of electrons at a phosphorescent screen; also the display device with attached keyboard called a terminal

currency - the flow by which all of the state variables in a model system are connected and moved between compartments according to a particular rate; examples are biomass, water, and energy

debug - to detect and correct errors in a program or computer memory

direct access - refers to a peripheral memory unit or retrieval process in which the time required to retrieve an item of data is independent of the location of the item; also known as random access

disk - see disk storage

disk file - an organized collection of records held on a magnetic disk

disk storage - an external computer storage device consisting of one or more disks spaced on a common shaft and magnetic heads mounted on arms that reach between the disks to read and record information on them

documentation - the written specifications of a program indicating program goals, memory requirements, data structures, and algorithms; the description and format of data and results

field - basic areal unit of the basin-scale version of SPUR

file - a collection of records each of which can be referenced according to location in a file (see also disk file)

fistulated - refers to an artifical opening in the rumen or esophagus of a herbivore through which a portion of the animal's forage may be obtained in order to estimate the diet botanical composition of the animal

formatted - the specific arrangement of data on a printed page, card, tape, and so on, to meet established presentation requirements (see unformatted)

FORTRAN - acronym for the FORmula TRANslation programing language; a family of procedure-oriented languages used mostly for scientific or algebraic applications

function - in FORTRAN, a special kind of subprogram which returns a computational value whenever it is called

functional group - an agglomeration of simulated plants sharing one or more characteristics;for example, warm-season grasses are grasses with the C_4 dicarboxylic acid photosynthetic pathway

gauge catch - the amount of precipitation intercepted by a collecting device such as a rain gauge

graminoid - resembling the grasses; a grass species

halophyte - a plant living in saline conditions; a plant tolerating or thriving in an alkaline soil rich in sodium and calcium salts

heterotroph - an organism which must obtain nourishment from exogenous organic material; an organism unable to synthesize organic compounds from inorganic substrates

hygrohalophytic - refers to a plant or plant community which grows in soil characterized by water which is saline

input - the process of entering information into a computer; the data entered into a computer

interpolation - estimation of intermediate surface values using a functional form which reproduces exactly known data values

iteration - a single execution of a set of instructions programed for repetition in a loop

kilobyte (K) - a unit of memory representing 1,024 bytes, abbreviated by the symbol K as in 64K for 64 kilobytes

least squares - a method of estimation for which the best result is that yielding the minimum value for the sum of the squared deviations between, in the case of multiple regression for a trend surface, the actual trend values

linear interpolation - the estimation of a surface with values at each data point weighted according to the inverse of its distance from the interpolated point

loop - a group of instructions in a program designed to be repeated usually with address modifications changing the operands of each iteration

magnetic core storage - a computer storage system in which each of thousands of magnetic cores stores one bit of information; current pulses are sent through wires leading to wires threading through the cores to record or read out data; the main memory of a computer; also known as core memory or core storage

memory - an organized set of locations in which a computer can store and find data and instructions

mesic - pertaining to conditions of moderate moisture or water supply; moist habitats

mesohalophytic - refers to a plant living in moderately alkaline soils rich in sodium and calcium salts

mesophytic - refers to a plant thriving under environmental conditions of moderate moisture and temperature, without major seasonal fluctuations

model - an abstraction of a system, in this case, a rangeland ecosystem; see also SPUR

model component - see component

parameter - a user input value which controls the shape or amplitude of a model function or determines the execution path within the model

peripheral - a device that may be added to a computer to provide additional data storage or to receive or display data; also known as peripheral device

photosynthesis - the biochemical process that utilizes radiant energy from sunlight to synthesize carbohydrates from carbon dioxide and water in the presence of chlorophyll

plot - a spatial representation of data generated by an output device such as a digital plotter or line printer

plotter - computer hardware; a device that produces pen or electrostatic plots of data stored in computer memory

polynomial - a linear combination of the products of integer powers of a set of variables

program - a set of declarations and logically organized instructions coded in a computer language in order to direct the operation of a computer

propagule - any part of an organism, produced sexually or asexually, that is capable of giving rise to a new individual

random access - see direct access

range site - see site

record - instructions or declarations or a variable or group of variables on a single line of data or program code; equivalent to one 80-column card

residual - in trend surface analysis the difference between actual and trend surface elevations of a point

ripe snow - snow in a snowpack at or about 32 degrees fahrenheit which is about to melt

run - see simulation experiment

scratch file - used in the formal OPEN statement in conjunction with the STATUS keyword; the file written to the user-specified device is opened and closed and deleted at the termination of execution

senescence - the biological process of aging

simulation experiment - one cycle of the SPUR model beginning with the command to execute and ending with the FORTRAN STOP message

sink - a buffering reservoir capable of absorbing or receiving the currency moving within a system without undergoing significant change

site - area of a field or pasture with specific soil, hydrologic and vegetation characteristics; the unit of simulation in the field-scale version of SPUR

site specific - plant-component parameters which are different between simulated field or pasture sites; must be entered separately for each site in the simulation

software - programs and data utilized by a computer

spatial - the location of, proximity to, or orientation of objects with respect to one another

species specific - plant-component parameters which are different between simulated plant species; must be entered separately for each plant species or functional group

SPUR - acronym for Simulation of Production and Utilization of Rangelands; the name given to the model described in this document

state variable - a variable that, on being observed, tells the particular expression or condition of the system that is modeled

stochastic - pertaining to random variables

submodel - see component

subprogram - a part of a larger program which can be converted independently into machine language; an external FUNCTION or SUBROUTINE

subroutine - a programed routine to which program execution can be passed by the main program or another subroutine; also called a subprogram

terminal - a device for communicating with a computer and usually including a keyboard and either a CRT or a printer

turgor - cellular or histological distension due to internal pressure

unformatted WRITE/READ - an input/output operation using binary values in internal storage; the values being read from or written to a user-specified device

user - anyone who requires or uses the services of a computer system or its products

variable - one or more alphanumeric words in memory manipulated by the program and identified by a label; may change in value as data are processed or program is executed

warm-season plants - see C_4 plants

word - a group of bits or bytes assigned to a unit of addressable memory which can be retrieved as a unit; the fundamental unit of storage for a digital computer

word size - the number of bits or bytes assigned to a word, thereby determining the accuracy of decimal numbers and the maximum absolute value of integers that can be stored in the word

xeric - pertaining to conditions of very little moisture or water supply; dry habitats

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